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MAJOR WEAPON SYSTEMS ACQUISITION AND LIFE CYCLE COST ESTIMATION: A CASE STUDY

by

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June 2001

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The Major Weapon Systems Acquisition Process requires the acquiring organizations to make long term resource commitments, whereas the defense budgets of many nations have declined over the past decade. Therefore, it is imperative for program managers and acquisition practitioners to make informed decisions not only considering the up-front costs, which are related to fielding of the system, but considering all the costs expected to be incurred throughout the system's planned life.

In this study, the major systems acquisition process,and its underlying concepts, life-cycle costing, and cost estimation techniques have been discussed, and the strategies that enable the PMO to optimize the life-cycle cost of the system are studied in a case study approach. The ATACMS IA missile system has been chosen as the study case. The life-cyle cost of the ATACMS IA missile system has been estimated; sensitivity and uncertainity analyses have been conducted by utilizing the Cost Analysis Strategy Assessment (CASA) estimating model in order to develop strategies which will eventually reduce the life-cycle cost of the system. The performance and cost figures used in the model are assumed by the author, due to sensitivity of the actual data. However, the model and the analysis results provide valuable guidance for the PMO, and the analysis methodology is applicable to any weapon systems acquisition program.

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MAJOR WEAPON SYSTEMS ACQUISITION AND LIFE CYCLE COST ESTIMATION: A CASE STUDY

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ABSTRACT

The Major Weapon Systems Acquisition Process requires the acquiring organizations to make long-term resource commitments, whereas the defense budgets of many nations have declined over the past decade. Therefore, it is imperative for program managers and acquisition practitioners to make informed decisions not only considering the up-front costs, which are related to fielding of the system, but considering all the costs expected to be incurred throughout the system's planned life.

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I. INTRODUCTION

A. BACKGROUND

The lessons learned from the history of the modern warfare imposes that technological superiority is one of the most important decisive factors in the conduct of warfare, providing a comparative advantage to the nation that owns it. Therefore, modernization of the armed forces, and acquiring innovative weapon systems has been a primary consideration in many nations' defense planning strategies.

On the other hand, the defense budgets of the most nations have been exposed to downsizing throughout the past decade, thus the most efficient and effective use of tax payers' money and providing the best value to the acquiring agencies has been the most important issue for defense acquisition organizations. Furthermore the fast proliferation and high obsolescence rates of technology complicate the requirements for the formal systems acquisition process: The weapon systems acquisition process should be robust to incorporate the latest technologies into system solutions, it should provide the best value to the acquiring organizations, and it also should realize best utilization of limited defense resources. One of the prerequisites for that kind of acquisition process is to adopt a life-cycle oriented approach in terms of cost, supportability, and operational availability.

In order to explore opportunities, apply theoretical knowledge base into practice, and test the life-cycle oriented approach to weapon systems acquisition decisions; this study is performed. The thesis studies all the issues that are associated with adoption of

the life-cycle oriented approach; then estimates the probable Life-cycle Costs (LCC) and expected operational availability of a major weapon system; and analyses the parameters that affect the LCC and operational availability of the system utilizing a case study approach. The ATACMS IA Missile System Acquisition Program has been adopted as the study case.

B. THE RESEARCH QUESTIONS

1. Primary Research Question

What are the elements of the LCC for the major weapon systems and what are the primary cost drivers? Are they controllable, if they are, what are the methods available, and what are the effects of performance improvements in system reliability, supportability, and maintainability; and in the logistics processes and organizations associated with the system on total ownership costs and system operational availability?

2. Secondary Research Questions

1. What is the relationship between the system reliability and maintainability, and the operational availability and LCC?

2. What are the effects of the learning and production rates on system acquisition costs?

3. What are the effects of Innovative Business Practices, such as Integrated Product and Process Development (IPPD) on system LCC?

4. What are the problems experienced in the traditional major weapon systems acquisition process?

C. SCOPE, LIMITATIONS

The study is conducted to explore the LCC drivers for the major weapon systems, and the available techniques and practices that would enable program managers to optimize system LCC within the framework of case study on the ATACMS IA missile system. The cost and performance data figures pertaining to the system are assumed by the author rather than being actual values.

D. ORGANIZATION OF THE THESIS

This thesis is divided into five chapters. Chapter I provides the background, the research questions, and the scope of the study.

Chapter II presents a comprehensive overview of the major weapon systems acquisition process, the inherent problems in the process, the solution approaches adopted by DoD to overcome those problems; an in-depth discussion of system development and support processes, such as the systems engineering process, supportability analysis, Integrated Product and Process Development (IPPD) approach etc; and then introduces life-cycle costing approach for major weapon systems.

Chapter III builds the body of knowledge for cost estimation including discussion of estimating techniques, estimation methodology, and estimation tools such as learning and production rate curves, sensitivity analysis, and cost risk analysis.

Chapter IV includes the application of life-cycle cost estimating process to the ATACMS IA Missile System, and analyses such as sensitivity and cost uncertainty for estimated life-cycle costs. Finally, Chapter V presents the conclusions and recommendations derived from the study.

II. OVERVIEW OF MAJOR SYSTEMS ACQUISITION PROCESS AND CONCEPTS

This chapter of the thesis is organized in order to build a knowledge base about the major systems acquisition process, including the new process mandated by the rewrite of DoD 5000.1 dated October 2000. These include the system development process, its underlying concepts, and sub-processes such as supportability analysis; and life-cycle costing, and the effects of innovative business practices on system LCC.

A. MAJOR SYSTEMS ACQUISITION PROCESS

A major system can be described as

> ....a combination of elements that will function together to produce the capabilities required to fulfill a mission need. The elements may include hardware, equipment, software, or any combination thereof, but exclude construction or other improvements to real property. [Ref. 1]

The acquisition process of those major defense systems is an iterative, complex, and detailed process, which can be assumed, from the global perspective, as a risk management mechanism that tries to satisfy the agency needs in the most mission effective and resource-efficient manner.

The historical roots of this formal acquisition process go back to the post-WW II era, however the process was articulated in 1972 by the Commission on Government Procurement. The commission's concept was adopted as a formal acquisition process by issuing The Office of Management and Budget (OMB) Circular A-109 [Ref. 2]. The

generalized form of the acquisition process is shown in Figure 1. The formal acquisition process, otherwise known as the life-cycle management process, is comprised of consecutive phases: namely, Requirements Generation, Concept Exploration, Program Definition and Risk Reduction, Engineering and Manufacturing Development, Production, Fielding/Deployment, Operational Support, and finally, Demilitarization and Disposal [Ref. 3]. In addition to those phases or system life stages, there are decision points, called milestones, before entering each phase in the acquisition process. Those milestones are developed to ensure the program's success throughout the system's life. At those milestones, the approvals by pertinent authorities to enter the subsequent phase are made and the exit criteria for that phase is specified in a document known as an Acquisition Decision Memorandum (ADM).

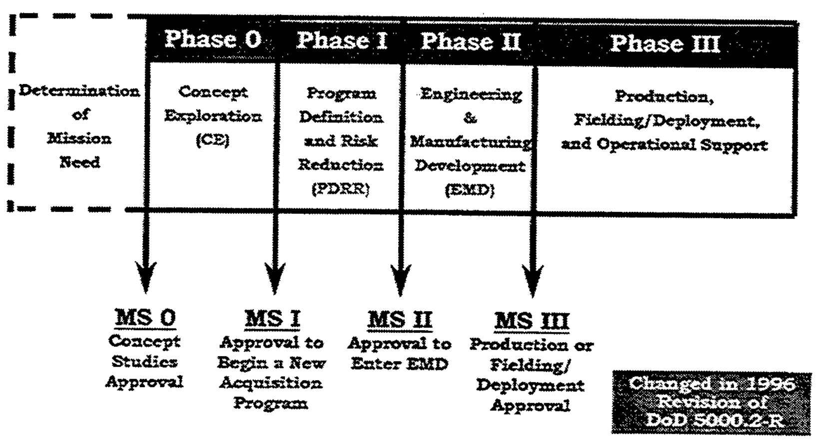

Figure 1: Traditional Acquisition Process **[From Ref. 3]**

This so-called iterative and detailed process gets started with the determination of a requirement or an operational need by the user community, in that context operational

agencies or strategic force planners, through mission needs analysis. The primary inputs to the mission needs analysis process are national military policy analysis, threat assessments for adversaries or potential adversaries, or changes in military strategy and doctrines. Technological improvements and innovations are also important inputs for the mission needs analysis, since improvements and innovations in science and technology may redefine how the military performs its missions both in organizational and technical terms. It is important to state at this point that all the new or redefined Mission Needs Statements (MNSs) may not result in new acquisition programs to develop material solutions. If non-material solutions, such as organizational restructuring or process reengineering, are available to satisfy defined needs without sub-optimization behavior, then these alternatives are preferred as more cost-efficient. If non-material solutions are proved to be ineffective, then a new system acquisition is considered the most viable option.

The historical facts and lessons learned about major acquisition programs denote that the success of the program is highly sensitive to correctly analyzing mission needs and carefully converting those MNSs into Operational Requirements Documents (ORDs). The gap between user-defined mission needs and formal MNSs and ORDs is filled by the discipline of system architecting and engineering [Ref. 4]. The system engineering process will be overviewed in a subsequent section. The technological/conceptual model of the acquisition process is devised to refine system requirements and specifications iteratively, rather than by providing system-specific parameters in the beginning of the

acquisition process, in order to incentivize technological and industrial innovation and develop alternative solutions and competition as much as is cost efficient.

After a through mission needs analysis and approval of the Mission Needs Statement, the decision to proceed into the Concept Exploration phase, i.e. Phase 0, is made and the Exit Criteria from the Phase 0 are established. The essence of this phase is exploring different alternatives to develop solutions to the mission needs. In that phase a formal Analysis of Alternatives, usually utilizing the Cost and Operational Effectiveness Analysis format, are conducted, and Operational Requirements Documents are generated for each concept that is selected to proceed with into the next phase. Provided it is cost-efficient, effective, and feasible, proceeding with more than one concept into the next phase is encouraged, since these will provide alternatives and increase the degree of competition. The primary tool for this and the subsequent phase, which is Program Definition and Risk Reduction, is using short-term parallel contracts with the responsive and responsible contractors, or with Federally Funded Research and Development Centers (FFRDCs).

In the Program Definition and Risk Reduction phase (PDRR), the eligible concepts from the concept exploration phase are narrowed down to design approaches and the prospective systems are evaluated closely by cost, schedule, performance, and supportability parameters. System prototyping, demonstrations, and early operational assessments, especially in virtual environments, are the primary tools to reduce risk, which is inherent in any system development. The cost drivers in the life-cycle of the

system are identified and the cost data to support program budgeting decisions are developed in that phase.

In Phase II, which is the Engineering and Manufacturing Development phase (EMD), the most promising, from the perspective of performance, cost, schedule, supportability from the PDRR phase, and the design approach, are evolved into a stable design. The producibility analysis of the solid design is performed concurrently, and the manufacturing techniques for the proposed system configuration are developed or maturated. The concurrent engineering approach, which will be discussed later, is utilized in that phase. This approach tries to evaluate design, producibility, and supportability issues concurrently, rather than iteratively. In order to test the proposed system's operational capabilities, an optimum quantity of system is manufactured during Low Rate Initial Production (LRIP), which also helps to develop realistic manufacturing cost data.

After operational testing and validation of the system, Low Rate Initial Production is evolved into Full Rate Production (FRP), which will incorporate any required modifications to the design; then system deployment starts. In this Operational Support phase, efforts are focused on sustainment of the system. Assessments will be made to evaluate the effectiveness of personnel, logistics support (e.g. spare parts supply and maintenance), and any potential cost-effective reliability improvements or modifications. At the end of the system's economical life, which is pre-planned during system development, the system is disposed out of service. The disposal and demilitarization

activity should not be considered as only dropping the system out of inventory, but should be considered as group of activities that aim to execute the disposal process with minimal negative impact to the environment, in accordance with applicable laws and regulations.

As stated in the beginning of this section, the underlying concepts of this acquisition methodology go back to the post-WWII era, when the major weapon systems are hardware-intensive and DoD has been the primary weapon technologies developer. But, the times have changed; now most major weapon systems are software-driven (an extension of the fly-by-wire-concept) and DoD is a technology integrator and user, rather than developer. The pace of technological innovation is very fast and difficult to keep up with. This paradigm shift profoundly affects the success of the formal acquisition process described above. Although it is not the primary topic of this thesis, the writer wants to briefly discuss the problems with the aforementioned acquisition process.

First of all, the nature of software development is very different from that of hardware development. On the one hand, hardware development follows a linear development cycle, which is in parallel with the acquisition process. On the other hand, software development efforts are spiral rather than linear. The problem arises in the synchronization of these two different development patterns in one acquisition challenge. Therefore the acquisition strategy for software-intensive major weapon systems must be tailored to solve those problems.

The other problem area is the paradox of the long cycle-time of the formal acquisition process versus high technological obsolescence rates. In today's acquisition

environment, the average acquisition time for major weapon systems is 8 to 10 years. DoD has developed initiatives such as cycle-time reduction or the open systems approach. Although both are very promising in the quest to resolve the issue of technological obsolescence, these initiatives alone are not sufficient to solve the problem. A more radical approach to reengineering the acquisition process is required. Birkler, et al. propose an alternative acquisition process to acquire state-of-the-art technology and innovative systems. This process is called the dual path acquisition methodology, and is depicted in Figure 2. The key objectives of that so-called process are rapid development of new operational and system concepts, acceleration of development and demonstration of new concepts at system and subsystem level, and providing early provisional operational employment of new systems well before completion of design stabilization and full operational testing. The so-called dual path process is devised to work in conjunction with the current acquisition process [Ref. 5].

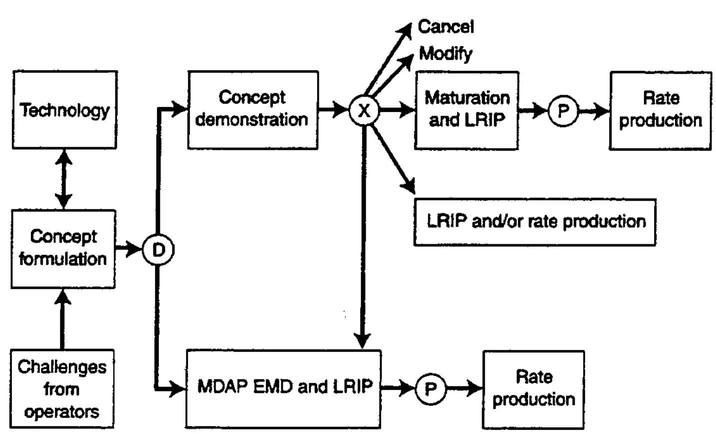

Figure 2: An Innovative Process Proposed by RAND [From Ref. 5]

Considering the deficiencies of the traditional acquisition process, DoD reengineered the process in May 2000. Basically, the new process separates technology development from system development, and is devised in order to enable DoD to acquire innovative systems in shorter times at reasonable cost (Figure 3). [Ref. 6] Realization of shorter acquisition lead times is specifically emphasized in the process because of high obsolescence rates and proliferation of weapon system technologies. The cost, performance and schedule risks in the systems acquisition process have been addressed by promoting use of mature technologies, evolutionary requirements generation (achieving initial operational capability as soon as possible and developing open systems architectures rather than finishing the full system development phase), and developing cost objectives and sticking to those objectives throughout the systems acquisition process. At highest level, the new process includes three phases: pre-system acquisition, system acquisition, and sustainment. The pre-system acquisition phase is comprised of concept and technology development efforts; those efforts and verification of technological maturity are the responsibility of the science community rather than acquisition organizations. Formal acquisition programs start only after the science and technology organizations verify the maturity of technology. The system acquisition phase is comprised of system integration, demonstration, manufacturing, and deployment to achieve Initial Operational Capability (IOC). The acquisition program can commence at any point before production starts, rather than following a mandatory sequential path as in the old acquisition process. The last phase of the system life-cycle in the new process is the sustainment phase, which comprises operations and support activities with Full

Operational Capability (FOC). An in-depth evaluation of the new process will not be discussed because it is beyond the scope of this thesis.

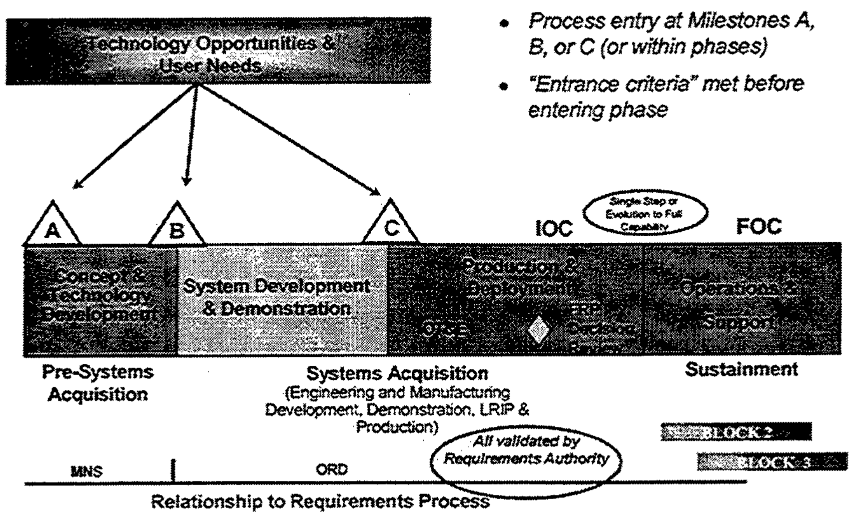

Figure 3: The New DoD Acquisition Process **[From Ref. 6]**

B. SYSTEMS ENGINEERING PROCESS AND RELEVANT CONCEPTS

1. Systems Engineering Overview

Systems Engineering can be defined as

> ...an application of scientific, engineering, and managerial efforts to transform an operational need into a description of system performance parameters and a system configuration through the uses of iterative process of definition, analysis, synthesis, design, test and evaluation; integrate related technical parameters and ensure compatibility of all physical, functional and software interfaces in a manner that optimizes the total system definition and design; and integrate reliability, maintainability, safety, survivability, human engineering and other such factors into the total engineering effort to meet cost, schedule, supportability and technical performance objectives. [Ref. 7]

An alternative definition of the systems engineering process is such that

> ...an interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and life-cycle balanced set of system, people, product, and process solutions that satisfy customer needs. Systems engineering encompasses the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for, system products and processes; the definition and management of system configuration; translation of the system definition into work breakdown structures; and development of information for management decision making. [Ref. 8]

These two alternative definitions of systems engineering give insight into the fundamental characteristics of systems engineering practice, which are discussed in the following paragraphs.

Systems engineering utilizes a top-down approach and views the system as a whole, in contrast to the bottom-up approach, which is utilized in traditional engineering disciplines such as mechanical or electrical engineering. The primary focus areas in the systems engineering process are addressing user requirements in all levels of development efforts, and interfaces, either subsystem level or system and beyond system level, which encapsulates a system-of-systems concept. The difference in approaches has significant effects in practice such that the top-down approach uses hierarchical abstraction models to ensure successful interface of the subsystems, but does not warrant physical realization of subsystems or components; on the other hand the bottom-up approach guarantees the physical realization of components or subsystems, but does not ascertain successful interface between subsystems or components of a system. However both methodologies are not substitutes for each other, rather they are complementary

methodologies in such a way that first and continuously utilizes systems engineering methodologies in order to ensure satisfaction of user requirements and successful interface between system elements, and reduce complexity and total ownership costs that utilizes traditional engineering methodologies to realize the existence of components or subsystems of a system. [Ref. 9]

From the systems engineering perspective, it is very crucial that system developers understand user needs well, and develop system requirements definitions correctly, based upon those well-understood user requirements; the ultimate goal of system development efforts should be user satisfaction in a cost-effective manner [Ref. 9]. The system requirements must be well defined, specified in terms of functional performance parameters, and be traceable throughout all levels of the system. The lack of understanding user requirements correctly in the initial phases of the system development effort may lead to very cost-intensive engineering changes in the succeeding phases of system development. The decisions, based on perceived user needs, in early stages of system development efforts when the system specific knowledge is limited, determine the cost behavior and effectiveness in terms of both operational and logistical support of the system. At the same time, the ease of system configuration change decreases and the resource requirements for implementation of the configuration changes increases exponentially throughout the system life. This system development pattern is shown in Figure 4.

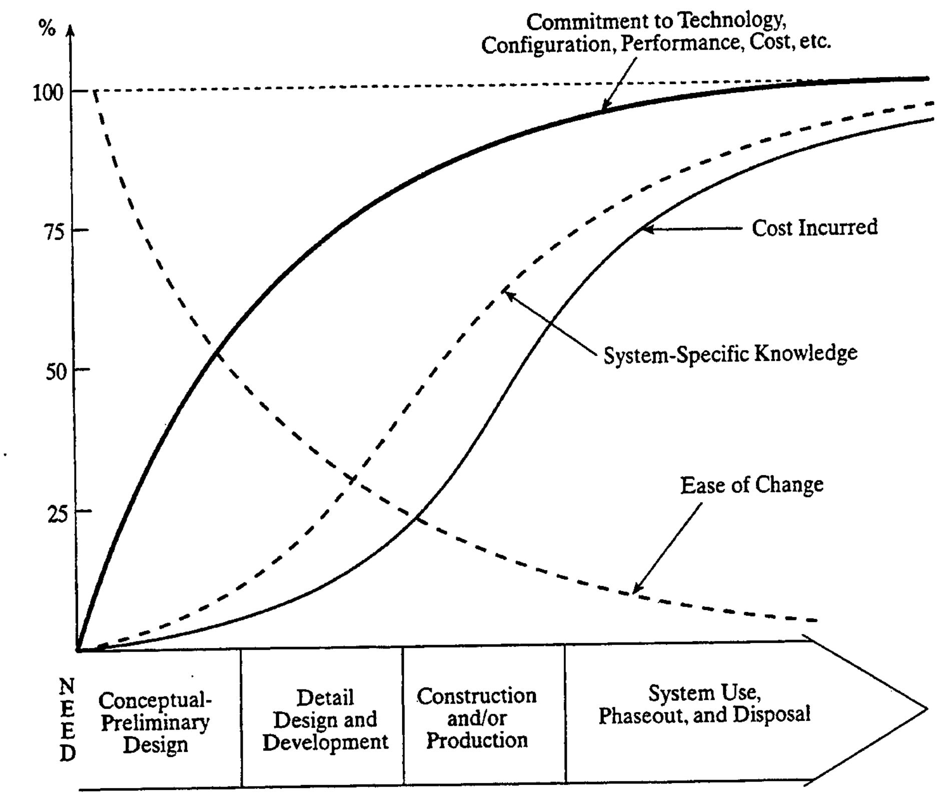

Figure 4: System Development Pattern **[From Ref. 9]**

The Systems engineering process is a life-cycle oriented approach, which addresses all phases of system life from conceptual design to disposal. In traditional product development or engineering approaches, the emphasis has been primarily on system acquisition and design activities, and this approach has generally resulted in sub-optimization without considering the total life-cycle cost of the system. On the other hand, in the systems engineering approach the development efforts are focused on reducing total ownership costs while increasing overall system effectiveness.

Systems engineering is inherently an interdisciplinary approach and requires teamwork throughout all phases of the system development cycle in order to ensure that all design objectives and performance parameters are addressed in an efficient and effective manner. This so-called team approach resulted in the Integrated Product and Process Development (IPPD) technique, which will be addressed in another sub-section.

2. Systems Engineering Process

Although there is some agreement in academia and industry on the fundamental characteristics of the systems engineering process, there are many different methodologies available in different domains [Ref. 9]. The variance in the methodologies comes from either the diverse backgrounds of systems engineering practitioners and application areas or continuous process improvement efforts. In this subsection, the most popular methodologies will be briefly evaluated.

a. Generic Systems Engineering Process Model

This generic systems engineering process model primarily reflects hardware system development efforts and is derived from the hardware product development waterfall. The process includes inputs and outputs; requirements analysis; functional analysis and allocation; synthesis; verification; and feedback mechanisms between those sub processes (Figure 5). This process model has been very successful in the past in developing hardware-intensive systems such as major weapon systems, but with the increasing percentage of software applications in system architectures, the need

for a different process, which will reflect a software development pattern, has been evident.

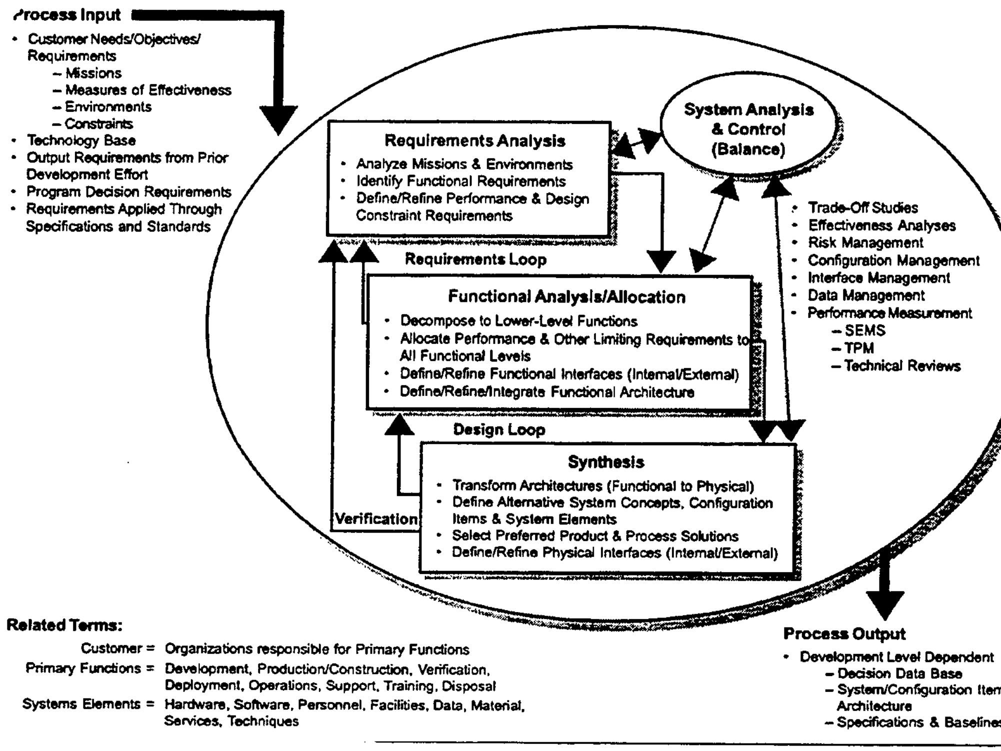

Figure 5: Generic Systems Engineering Process [From Ref. 7]

b. Spiral Development Model

As mentioned in the previous sub-section, this development model has been born out of the need for a different process, one which will reflect the development pattern of software or software-intensive systems [Ref. 4]. The structure of the process reflects one of the fundamental paradigms of software engineering: The software or software-embedded systems must be grown rather than built, which addresses the evolutionary, time-phased development nature of software or software-embedded

systems. Basically, the spiral process prescribes developing the product baseline and realization of IOC as soon as possible, and evolution of the product according to the operational difficulties and needs experienced. It has been argued that this approach would dramatically reduce system development cycle-time and allow the incorporation state-of-the-art technologies into later versions of the system. In fact, DoD has modified its traditional acquisition process to realize those objectives. The spiral process model is shown in Figure 6.

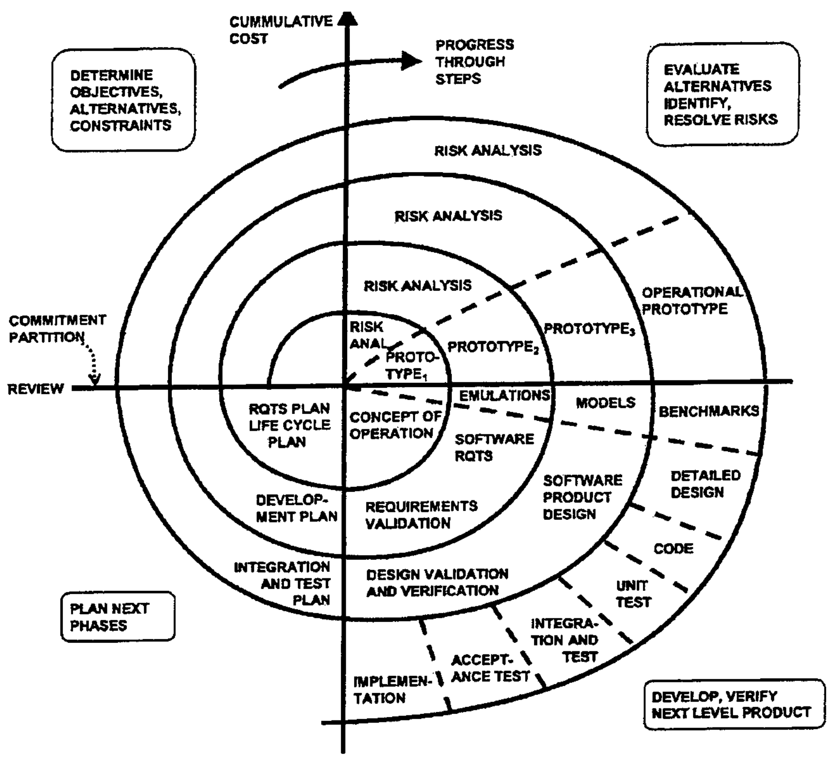

Figure 6: Spiral Process Model **[From Ref. 9]**

c. *V Process Model*

The fundamental concepts of this model are borrowed from the National Aeronautics and Space Administration (NASA) Software Quality Assurance Program (SQAP), which was used in the 1980's by the agency; the process is also called "technical aspect of project management" [Ref. 10]. As shown in Figure 7, the model is comprised of two major sub-processes, namely the decomposition and definition sub-process, and the integration and verification sub-process, respectively, for each arm of the V shape. The model is intentionally designed to develop direct correlation between both arms of the V shape at each decomposition level, so that once the system specifications are determined in the left side of the V, the verification method for those specifications must be determined simultaneously. This model is a meta-process for systems engineering management and requires the tailored application of the generic systems engineering process at each level of decomposition.

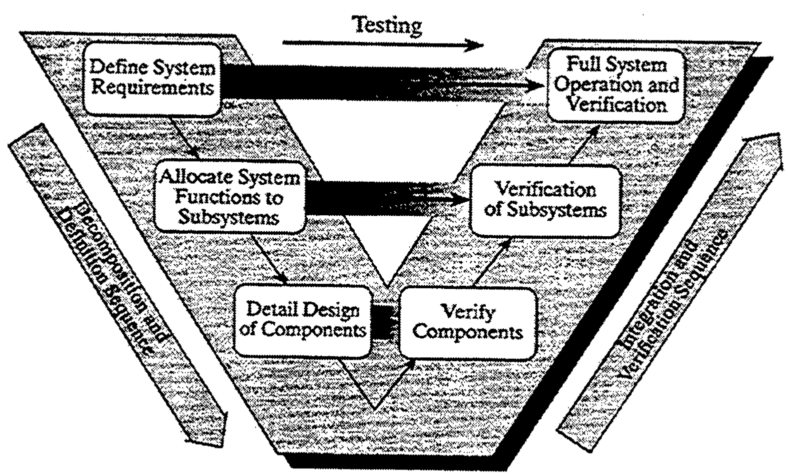

Figure 7: V-Process Model **[From Ref. 10]**

d. Hartley-Pirbhai Methodology

Hartley-Pirbhai methodology has been born out of the need to solve problems encountered in the integration of the systems' software and hardware elements in the avionics industry; it has been utilized in many real-time software-embedded system development efforts in different industries [Ref. 11]. This methodology is complementary to spiral development model, rather than an alternative systems engineering process and should be used concurrently with the spiral development model.

The underlying assumption for the methodology states that both hardware and software components of the system are highly interrelated, and in order to successfully perform their intended function, they must integrate well. Based on this assumption, the methodology treats the system as a whole, including both software and hardware components, and develops system functional and architectural specifications through system requirements and architecture models in an integrative manner, rather than following different paths characteristic of traditional system development methodologies. In the highest level, the methodology consists of a requirements model and an architecture model, which define respectively, what the system should do (functions) and how the system should perform those functions (architecture).

3. Open Systems Architectures

Open Systems Architecture (OSA) has been defined as a system development concept "that implements sufficient open specifications for interfaces, services, and

supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability" [Ref. 12]. In more explicit words, OSA is a system or product development strategy that enables the system developers to specify modular, interchangeable, upgradeable systems that will be adaptable to technological innovations and changes in the user requirements in a resource-efficient manner.

This system development strategy together with Single Process Initiative (SPI), which tries to eliminate the differences between commercial systems production methodologies and defense systems production methodologies, and development of flexible manufacturing systems are effective enablers in reducing total ownership costs and acquisition cycle-times for the defense systems. As a matter of fact, the introduction of a new major system acquisition process, which adopted a time-phased requirements and incremental system development methodology, makes the application of OPA an imperative for acquisition strategy planners.

4. Integrated Product and Process Development Concept and Concurrent Engineering

The Integrated Product and Process Development (IPPD) concept is a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams, which are called Integrated Product Teams (IPT) in order to optimize the design, manufacturing and supportability processes. IPPD

facilitates meeting cost and performance objectives from product concept through production and field support [Ref. 13]. From the technical viewpoint, the definition connotes the systems engineering process, however the IPPD concept takes the teamwork orientation of the systems engineering process further, to include not only design and logistics-oriented members, but also include the budgeting and business-oriented people (such as contracting officers or contractor's personnel) into the product development teams; the IPPD concept aims to improve product-related processes by concurrently including design, manufacturing, and support. The latter objective of the IPPD concept is called "concurrent engineering."

The size of the IPTs should be based on the nature of the system to be acquired, but either overcrowding or understaffing the teams may lead to undesired results in the application of the concept. Overcrowding may slow down the decision-making process in the teams and cause longer acquisition cycle-times and inefficient use of limited resources; whereas understaffing the teams may lead to omission of important perspectives that may result in catastrophic consequences such as unsatisfied agency needs, program delays, or unsustainable systems. The lessons learned from the major acquisition programs make it imperative that the team members have adequate training and the required skills for effective team dynamics. The other point that deserves consideration is that adding new members to any system development team, especially for software-intensive systems, to expedite the acquisition process makes acquisition cycle

time longer rather than shortening it, since generally the most efficient team members are assigned to orientate the newcomer to the process or team. [Ref. 14]

5. Configuration Management And Engineering Changes

The concept of Configuration Management (CM) arises from the need to evaluate, and track the changes made on system specifications mandated either by changes in initial requirements or technological effects, such as unavailability of required technology and manufacturing processes, or development of more mission-effective or cost-efficient parallel technologies; and to ensure the successful integration of those changes into the whole system configuration. CM can be regarded as an umbrella activity that manages the changes throughout the system life from system development efforts to sustainment. Before discussing the CM functions, it is helpful to overview briefly the drivers of configuration changes, the nature of the changes, and their effects of those changes on total system ownership costs.

One of the major drivers for configuration changes during system life is a change in the requirements which started the acquisition program. The requirements generation and system engineering processes in the DoD acquisition process are structured to minimize substantial configuration changes in the system through validation of requirements at all levels before beginning system development efforts. However, experience shows that there have generally been modifications in system requirements, especially in changing threat environments. The changes in requirements stem either from the uncertainty in mission environment or changes in the operational doctrines. The

new DoD acquisition process, which is overviewed in the first section of the chapter, adopted evolutionary requirements and open systems architectures concepts to deal with problems stemming from this domain. However, even with adoption of those concepts, the application of changes in system mission needs to system requirements may prove to be costly, especially at later stages of system development, since mission needs changes directly affect capstone system requirements.

The other family of drivers for system configuration change arises from the system and manufacturing technology domains. The writer prefers to call these kinds of change drivers as technological effects that may have either positive or negative triggers behind them. For example, the unavailability of required system technologies or manufacturing technologies might lead to substitution of more mature and available ones, thus changing the system configuration becomes imperative. On the other hand, incorporation of some other parallel technologies, either to the system configuration or to the manufacturing process, may prove to be more mission-effective and cost-efficient through value engineering efforts, thus changes in system configuration become unavoidable.

The main determinants that affect the cost of configuration changes are the timing and magnitude of the configuration change. As Figure 4 depicts, the cost of change increases exponentially as the system life progresses; as a rule of thumb, it requires 10 times more resources to implement a configuration change during the production or sustainment phases than implementation of a similar change during the system

development phase. The other determinant of configuration change cost is the magnitude of the change. The required or proposed configuration changes may be either be local changes i.e. only at subsystem level that does not affect whole system behavior and does not require configuration changes in other levels, or global changes i.e. that require reconfiguration of other subsystems and the whole system for successful integration. However, the lessons learned show that most of the configuration changes prove to be latter ones, and require adjustments at different levels, especially in software-embedded systems. The relationship between magnitude of change and cost of change is shown in Figure 8.

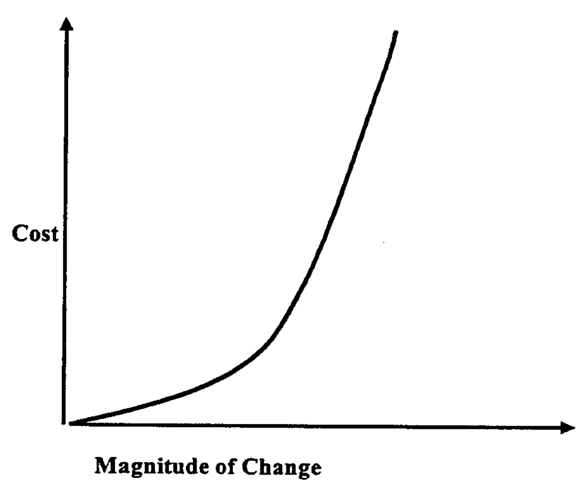

Figure 8: The Cost versus Magnitude of Change **[Developed by the Author]**

The function of configuration management has a dual purpose: the first being to ensure the realization of developed system specifications in the final product, product descriptions, and system-related documents such as technical or operational manuals; and

the other being to ensure successful integration of specification changes made either at subsystem, component, or system level into system specifications and incorporate those changes into system-related documents or procedures such as system logistics support functions. As stated in the beginning of the sub-section, configuration management is a continuous activity throughout the system life-cycle; therefore configuration management functions should be performed by a formal organization within the program office and system modification activities, even in the sustainment phase, should be coordinated with that organization.

C. SYSTEM LIFE-CYCLE COSTS AND COST AS AN INDEPENDENT VARIABLE (CAIV) CONCEPT.

In this section, the life-cycle costing concept and its elements, and the effects of system reliability and innovative business processes in systems acquisition upon system life-cycle costs will be briefly discussed. The discussion will be based on theoretical approaches rather than empirical studies, and is intended to build an adequate reader knowledge base concerning those concepts. Throughout this thesis, the terms "life-cycle costs" and "total ownership costs" will be used interchangeably.

System life-cycle cost is defined as total cost to the acquiring agency of the acquisition and ownership of the system over its full life. It includes cost of development, acquisition, operation, and where applicable, disposal [Ref. 15]. In the acquisition and cost estimation literature, there are many cost terms, such as flyaway costs, weapon system costs etc, defining some portion of system total ownership costs that may cause

misunderstandings for readers who are outside the acquisition community. Figure 9 shows the relationship and hierarchy of those cost terms.

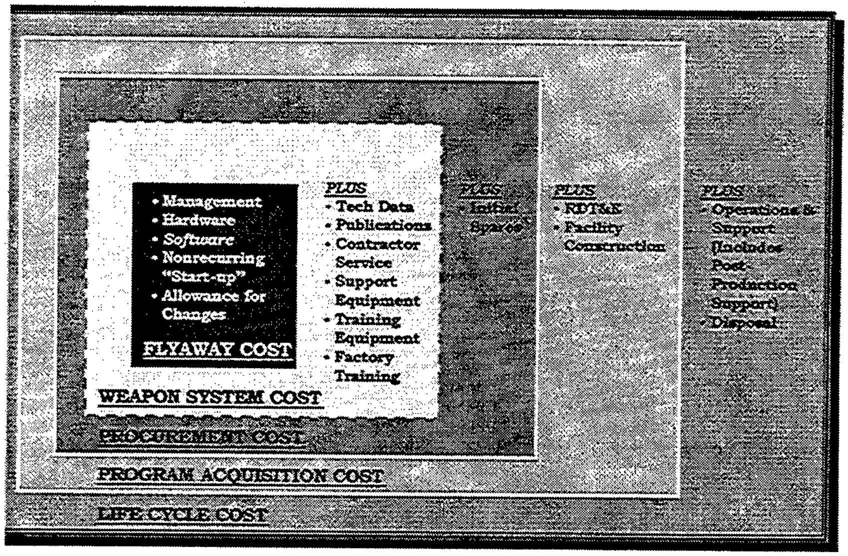

Figure 9: Cost Terminology **[From Ref. 16]**

As indicated in Figure 9, Design-to-Unit-Production-Cost (DTUPC) is comprised of basic unit procurement cost including recurring production costs, but excluding initial spares costs. DTUPC plus non-recurring production costs comprise system flyaway costs. Weapon system cost is formed by addition to flyaway costs of any item costs required, such as support equipment, but the initial spares costs are excluded in weapon system costs. Addition of initial spares cost to weapon system costs comprises system procurement cost. Program acquisition cost is procurement cost plus Research, Development, Test, and Evaluation (RDT&E) cost and facility construction costs, if required, for system operation. Program acquisition cost plus system operation and

support, and system disposal cost, if applicable, is called system life-cycle cost or total ownership cost.

As stated in the previous section, the decisions made in the early stages of the system development effort while there was limited system-specific knowledge, determine the life cycle-cost behavior of the system. However, the costs are incurred at the later stages of system life, they are established by system development decisions. These system development patterns are shown in Figure 4. One of the acquisition reform initiatives, which is the Cost As an Independent Variable (CAIV) concept, is formulated to control resource commitments during system development efforts. Basically, the CAIV concept can be defined as developing life-cycle cost targets for the system to be acquired and constraining the system design decisions or trade-offs by the target cost of system ownership. Prior to the CAIV concept, the Design-to-Cost approach (DTC) was very popular in the acquisition community, but DTC approach has been primarily concentrated on controlling system procurement costs, rather than system life-cycle cost, whereas the CAIV is life-cycle oriented, which tries to optimize the entire system life-cycle cost rather than a portion of life-cycle cost. The difference between these two approaches has profound effects on system cost behavior. For example, improving system reliability and maintainability to optimal levels may increase the cost of system development efforts, which is not desirable from the DTC perspective, but improved reliability and maintainability will, in long run, eventually decrease total ownership costs.

1. Discussion of System Life-Cycle Cost Elements

As defined above, system life-cycle cost (LCC) or system total ownership cost (TOC) is total of all the costs incurred during system life. The major components of the system LCC are Research, Development, Test, and Evaluation (RDT&E) costs; Investment Costs which include Military Construction (MILCON) costs, and Production and Deployment (P&D) costs; Operation and Support (O&S) costs; and Demilitarization and Disposal (D&D) costs. As shown in Figure 10, the distribution of those LCC elements throughout typical system life is such that: 10% of LCC is RDT&E, 30 % of LCC is Investment Costs, and 60% of LCC are O&S and D&D costs respectively. As it is clear from the proportional cost element contribution figures, the highest cost driver in LCC is O&S costs; therefore the system developers put special emphasis on reduction of O&S costs through improving system reliability to the extent feasible, and decreasing manning and logistics support requirements for the system. The "smart ship" program in the US Navy is good example of those kinds of efforts. The effect of design factors such as reliability and maintainability on LCC will be discussed comprehensively in Section D.

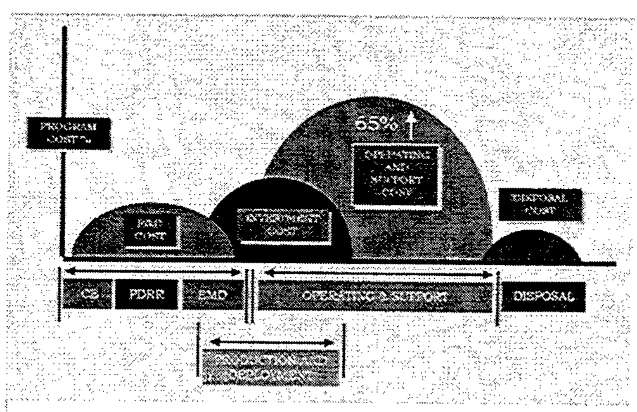

Figure 10: LCC Distribution **[From Ref. 16]**

In the following sub-sections, major LCC components will be discussed and their cost elements will be listed briefly.

a. RDT&E Costs

The costs associated with system development efforts constitute RDT&E costs and are incurred during system development and testing efforts. The software component of any system actually is produced in that period since software reproduction costs are ignorable relative to costs incurred during software development efforts. Generic RDT&E Work Breakdown Structure (WBS) consists of those cost line items.

- Project management costs
- System test and evaluation costs
- Data collection and generation costs
- System engineering and integration costs
- Demonstration and validation costs
- Hardware research and development costs
- Software development costs
- Prototype manufacturing costs etc.

b. Investment Costs

Investment costs cover all the costs incurred to field the system to the operational units. We can classify investment costs into two major categories; military construction costs (MILCON), and Production and Deployment costs (P&D). MILCON

costs are associated with construction requirements in order to manufacture , operate , and support the system throughout the system life. P&D costs refer to costs incurred for manufacturing and deployment of the system into the operational units. They include costs such as developing manufacturing equipment, production process control and quality assurance etc.; the recurring manufacturing costs; costs of system support equipment and training equipment; cost of initial spares; documentation; and the other costs required to make the system deployable. Generic WBS elements for Investment costs:

- MILCON Costs
- Production tooling and test equipment cost
- Production set-up cost for lots
- Pre-production engineering non-recurring costs
- Recurring production costs
- Support equipment cost
- Initial spares cost
- Transportation costs
- Training devices costs
- New or modified facilities costs
- Warranty costs etc.

c. O&S Costs

O&S costs are the total of the costs associated with operating and supporting the system through its operational life. As mentioned previously, the largest portion of the system LCC is incurred through its operational life, whereas the opportunity to control O&S costs is very limited in that phase of the system life-cycle. Generic Cost Element Structure (CES) of O&S costs is such that:

- Personnel (Operations, Maintenance, Training etc.)
- Unit level consumption (Consumable Materials, Energy Consumption, Spares Replenishment, Training Munitions etc.)
- Maintenance Material Costs (O-level, I-level, D-level)
- Sustaining Support Costs (Support equipment maintenance and replacement, Sustaining engineering support, Software maintenance costs etc.)
- Indirect Support Costs (Personnel Support, Installation Support)

d. D&D Costs

D&D costs are incurred at the end of system life, and associated with disposal of the system with minimal environmental effect. The increasing level of environmental awareness by public, restrictive environmental regulations, and security considerations make the appropriate disposal process an imperative.

2. Effects of Innovative Business Processes on Total Ownership Costs

So far, especially in section B, we have championed innovative business practices such as system engineering methodologies, concurrent engineering, integrated product and process development, and time-phased requirements approach etc. At this point, a pragmatic question rises in ones mind; what would be the effects of those practices on system LCC? Are internal rates of return (IRR) on investment for those practices large enough to compensate for costs related to application of those practices?

From the program manager's perspective, these innovative practices can be regarded both as effective variability and uncertainty reducers and as productivity improvement tools throughout the system's life. Although using group techniques, such as IPPD and IPTs, in any decision-making process may lengthen the decision-making period relative to one functional expert, the probability of erroneous decision-making that affects the future behavior of any system decreases dramatically utilizing the group process. Although resource-intensive, both in terms of time and financial resources, application of vigorous system engineering and integration methodologies during requirements definition and system development studies through will pay back via lower system LCC with less uncertainty as the Figure 11 indicates.

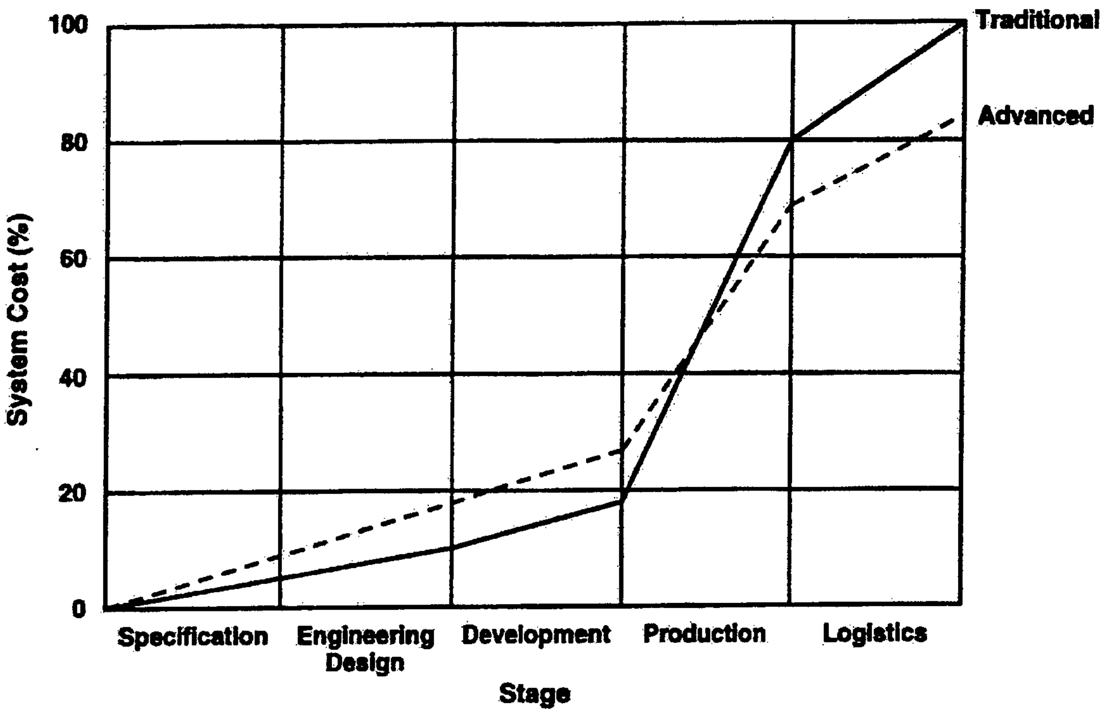

Figure 11: Impacts of Innovative Practices on System LCC [From Ref. 17]

D. SUPPORTABILITY ANALYSIS AND ILS CONCEPT

As mentioned in the previous section, system O&S costs constitute the major portion of the system LCC; therefore the writer concluded that it would be beneficial for the study to explore the factors that affect system O&S costs, the methodology for conducting predictive supportability analysis during system development efforts (which help system developers make design and performance trade-offs), and the tools currently available to conduct consistent supportability analysis. This section of the thesis is organized to realize that objective.

The paradigm in the system development process has been changed over the years from a "support the design" concept to a "design for supportability" concept. In other

words, supportability considerations have been inputs to the system development process rather than post-process considerations. The impacts of the paradigm shift are shown in Figure 12. The paradigm shift in the process has introduced the concept of Integrated Logistics Support (ILS) to the system acquisition environment. The ILS concept can be defined as

> ...a disciplined, unified, iterative approach to the management and technical activities necessary to integrate support considerations into system and equipment design; develop support requirements that are related consistently to readiness objectives, to design, and to each other; acquire the required support; and provide the required support during the operational phase at minimum cost. [Ref. 18]

Basically, ILS is a management function that tries to assure deployment of systems, not only with the desired functional performance, but also with expeditious and economically optimal supportability.

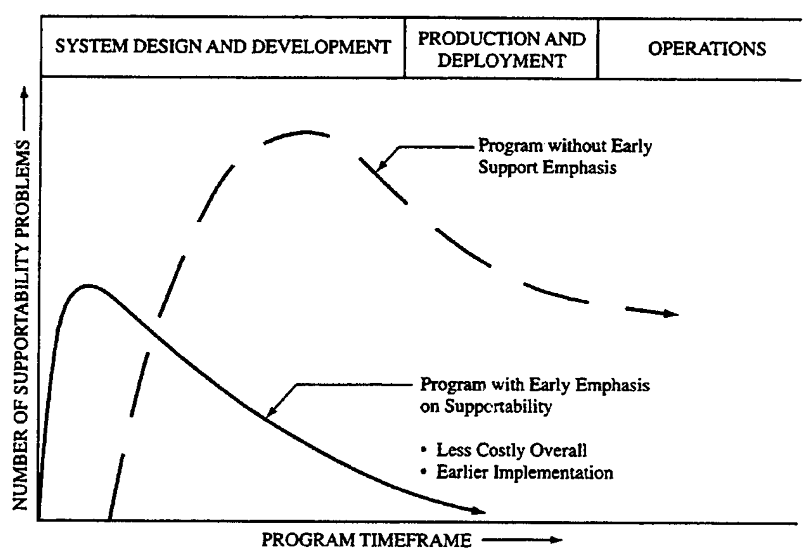

Figure 12: Impacts of Paradigm Shift in System Design **[From Ref.18]**

1. Design and Organizational Factors Which Affect System Supportability and Availability

The factors that affect system supportability can be classified into two interrelated categories; system design factors, which are inherent in the system design, and organizational factors that define the environment in which the system is operated and supported. Some of those design factors can be stated as reliability, maintainability, usability, and transportability; whereas organizational factors address the capacity and capabilities of the legacy organizational structure into which the system would be deployed, such as maintenance and supply organizations and their respective capabilities, operator and technician training mediums, or available transportation modes etc. As stated previously, those factors interact each other, and the result of this interaction can be regarded as operational availability (Ao). Basically, operational availability is the probability that a system or equipment will be available to operate satisfactorily under stated conditions in the actual environment when called upon. System Ao has been formulated as [Ref. 19]:

$$A_O = uptime/(uptime + downtime),$$

where uptime corresponds to Mean Time Between Maintenance (MTBM) and downtime corresponds to Maintenance Downtime (MDT), which includes Mean Maintenance Time (MMT), Logistics Delay Time (LDT), and Administrative Delay Time (ADT). Capacities

of relevant logistics organizations such as Cycle-Time (CT) and Throughput Rate directly affects LDT, and therefore Ao.

In following sub-sections, the design and organizational factors and their interactions that affect system supportability performance will be overviewed briefly.

a. Reliability and Spare Parts Determination

Reliability (R) can be defined as the probability of satisfactory performance for a system or product in a given period of time when used under specified operating conditions. As stated in the definition, system reliability has four elements: probability, time, satisfactory performance, and specified operating conditions. Satisfactory performance parameters, and operating conditions must be specified clearly in system ORD documents. The determinants of system reliability are system failure rate (λ), which is an inherent system design characteristic, and operating time (t). The reliability behavior of the system fits negative exponential distribution as long as Mean Time Between Failures (MTBF) of the system is constant during operational period, and expected reliability of the system at its operational life can be calculated by following equation: [Ref. 9]

$$R(t) = e^{-\lambda t}$$

When there is more than one system in any operational unit, the unit system reliability (composite reliability) can be calculated by inclusion of the total system number (k) in the above formula:

$$R(t) = e^{-k\lambda t}$$

System failure rate (λ) is the reciprocal of MTBF, and for some hardware systems the behavior of λ throughout system life is called the "bath tub curve" which is shown in Figure 13. As stated in Figure 13, λ is assumed to have a constant value during operational period of the system. However for software applications, λ behaves quite differently because of continuous software maintenance, i.e. bugging and debugging efforts (Figure 14). Overall system reliability is a function of the reliabilities' of subsystems and components, in other words the system configuration determines overall system reliability. From a reliability perspective, system components can be integrated in parallel or serial forms; parallel integration enables the system developers to increase system reliability through increased redundancy in the system. The analytical tools that help evaluate system reliability during system development efforts are Failure, Mode, Effects, and Criticality Analysis (FMECA); Fault Tree Analysis (FTA); critical useful life analysis; the stress strength analysis; and reliability growth analysis. In depth discussion of those analytical tools is beyond the scope of this study.

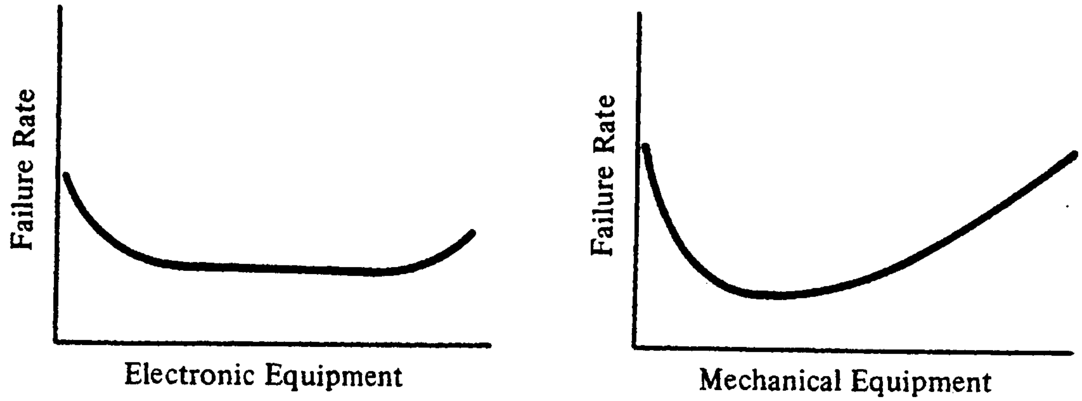

Figure 13: Hardware Component Failure Rate Behaviors [From Ref. 18]

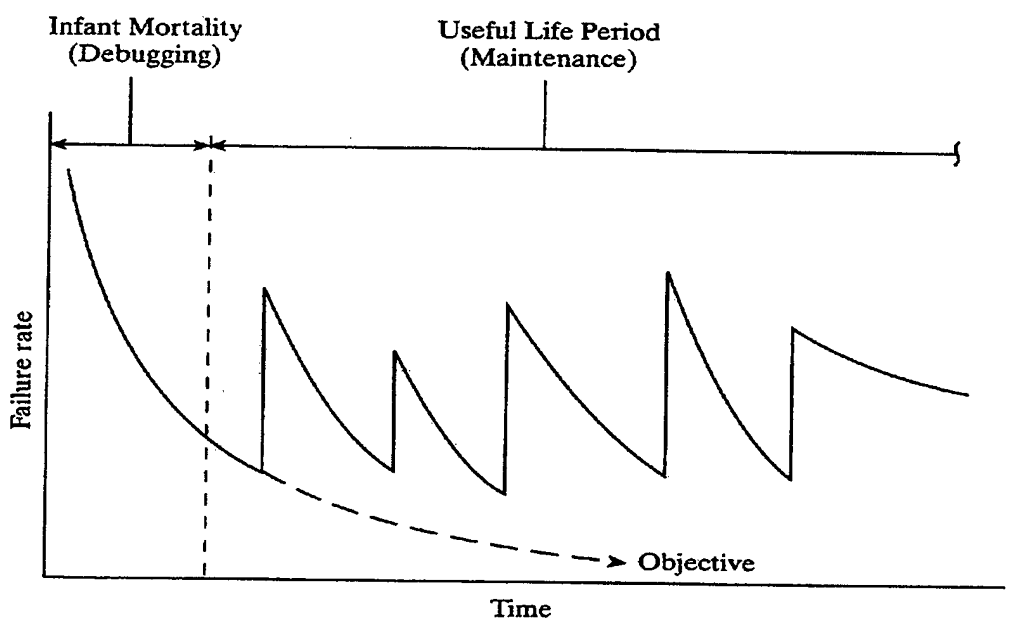

Figure 14: Software Components Failure Rate Behavior [From Ref. 9]

The number of system spare parts needed for the sustainment of the system is determined by the composite reliabilities of system components or subsystems, system operational period, and desired spares availability requirements. Spares

availability requirements indicate the probability of spares' availability when they are needed. The relationship between those parameters is indicated in the following formula:

$$P = \sum_{n=0}^{n=s} \left[\frac{R(-\ln R)^n}{n!} \right],$$

where S is the number of spare parts in the stock; R the composite reliability; and P is the probability of availability of the particular item's spare in stock when needed. The probability distributions derived from this formula fits Poisson distribution with mean value of – **lnR, i.e. k*λ* t,** as long as MTBF for the specified system or components follows exponential distribution. When determining spare numbers at unit level for a particular subsystem or component; first the desired protection level, that is P in above formula, and the operational period must be specified. The length of the operational period, t, depends upon different parameters such as stock replenishment period for expendable items, or Turn Around Time (TAT) for repairable items. Given the required parameters; protection level (P), and composite factor (k*λ* t), we can use cumulative Poisson table in order to determine the required number of spares for a particular component or subsystem. However, if large numbers of systems are involved in the spares determination process, the Poisson values approach to Normal distribution values as the result of the central limit theorem. In the cost estimation model, the spare parts cost will be calculated by this theoretical approach.

The system reliability is an important parameter that affects system O&S costs through spares requirements, maintenance actions, and the determination of the total

number of systems to be acquired in order to guarantee a certain number of systems are operationally available. The theoretical relationship between system reliability and TOC is depicted in Figure 15. As is clear from the Figure 15, the improvements in system reliability to the feasible extent, dramatically decreases system LCC; however pushing the envelope for system reliability beyond feasible technological levels may require huge commitments for R&D activities that the costs savings from improved reliability may not offset those commitments, so the system LCC goes up.

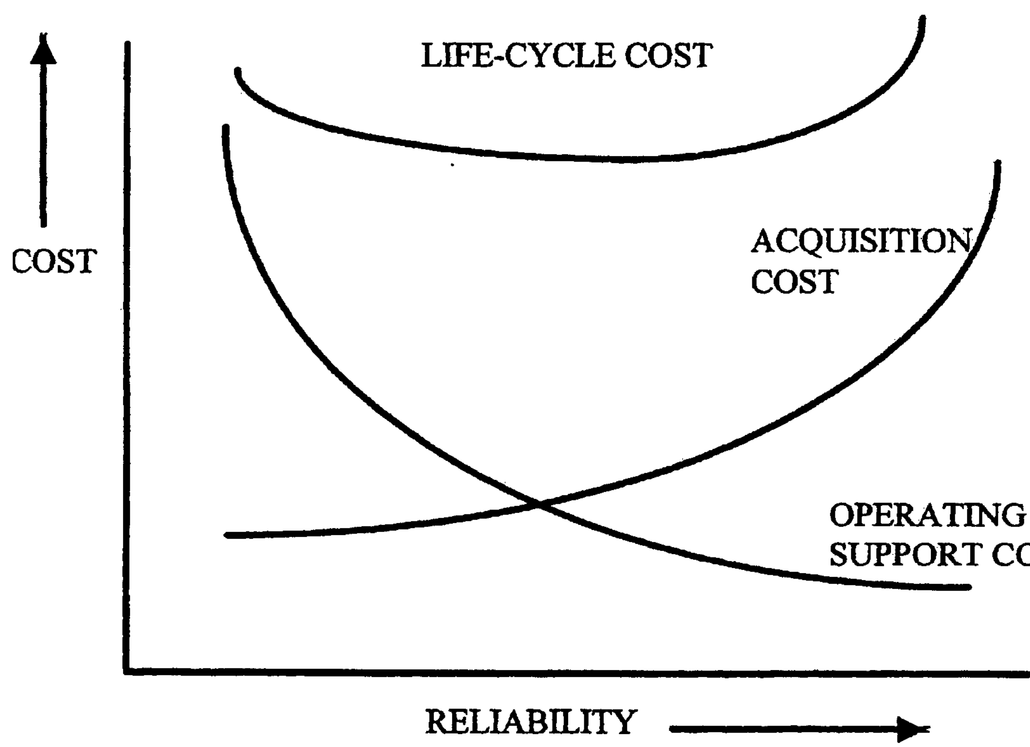

Figure 15: System Reliability and LCC Trade – Off **[From Ref. 15]**

b. Maintainability

Maintainability refers to the ease, accuracy, safety, and economy in performance of maintenance actions required to sustain the system during the operational use, and is an inherent characteristic of system configuration. One of the objectives in the systems engineering process is to develop a system or product that can be maintained effectively and safely, in the least amount of time, at least cost, with a minimum expenditure of resources (i.e. people, materials, test equipment, and facilities), without adversely effecting the mission effectiveness of the system. System maintenance requirements are derived from the system Maintenance Concept (MC), which is based on the system ORD. The system MC broadly defines levels of maintenance, repair policies, organizational responsibilities for maintenance actions, logistics support elements of the system, effectiveness requirements for system support, and environmental conditions.

All maintenance actions pertaining to a system can be broken into two general categories: **corrective maintenance** and **preventive maintenance** actions. Corrective maintenance actions refer to unscheduled maintenance actions performed to restore the system to a specified level of performance as a result of a failure. Preventive maintenance actions refer to scheduled maintenance actions performed to retain a system at a specific level of performance by providing systematic inspection, detection, servicing, or the prevention of impending failures through periodic item replacements. Preventive maintenance actions serve to keep the system in the inherent reliability performance level, rather than improving system reliability. Similar to hardware systems;

software maintenance actions are broken into two categories: **adaptive maintenance** and **perfective maintenance.** Adaptive maintenance refers to the continuing process of modifying software in order to make it compatible to changing requirements in the data or processing environment within the original architecture, whereas perfective maintenance refers to software modification efforts in order to enhance its performance through architectural evolution.

System maintainability is assessed through maintainability metrics, which can be classified into three categories: maintenance frequency metrics, maintenance elapsed-time metrics, and maintenance cost efficiency metrics. Maintenance frequency metrics are: Mean Time Between Corrective (Unscheduled) Maintenance (MTBMu), which is equal to MTBF on average for stable systems; Mean Time Between Preventive (Scheduled) Maintenance (MTBMs); and Mean Time Between Maintenance (MTBM), which is average time between all maintenance actions, calculated by the following formula.

$$MTBM = \frac{1}{1/MTBM_U + 1/MTBM_S}$$

Maintenance elapsed-time metrics refer to the time spent during performance of maintenance actions. Mean Corrective Maintenance Time (Mct) is the average time required to perform corrective maintenance actions, whereas Mean Preventive Maintenance Time (Mpt) refers to average time required to perform preventive maintenance actions. Mean Active Maintenance Time (M) is average elapsed

time required to execute preventive and corrective maintenance, and calculated by the following formula in which the "λ" and "**fpt**" refer to failure rate and scheduled maintenance rate, respectively:

$$M = \frac{(\lambda)(M_{CT}) + (fpt)(M_{PT})}{\lambda + fpt}$$

Maintenance cost efficiency metrics refer to the cost part of maintenance actions and include both labor costs and material costs. Although there is no standard metric for maintenance cost efficiency; the most useful of those metrics are: average material cost for per corrective maintenance action, average material cost for per preventive maintenance action, job skill requirements for maintenance categories at each maintenance level etc.

The enabling methods and tools utilized to develop, enhance, and test the maintainability performance of the system under consideration are: Reliability-Centered Maintenance (RCM); corrective vs. preventive maintenance trade-off analysis; repair vs. discard analysis; Level of Repair Analysis (LORA); Fault Tree Analysis (FTA); maintenance task analysis; and maintainability prediction techniques. In depth discussion of those methods and tools are beyond the scope of this study.

c. Usability

Usability refers to human interface with system, and is a determinant of system manning costs. Usability requirements for the system should be specified in the

system ORD, and should reflect the anthropometrical, psychological, and psychomotor properties of the prospective user population. The general objective in addressing usability requirements in system design is to establish system design criteria that will promote simplicity in operation and maintenance to the extent possible, in order to minimize personnel training costs; labor costs; probability of personnel induced system failures, and accidents, so that the system LCC can be minimized.

The most important usability metrics for any system are total number of personnel required to operate the system, required personnel skill levels, training requirements, human-induced failures and accidents, and the quantity of system-induced health problems in the personnel.

d. Transportability

Transportability of a system addresses the requirement for the system, subsystems or components to be transportable in effective and efficient manner within available transportation modes and vehicles, i.e. highway transportation, airway transportation, or water transportation; and is directly related to system dimensional and weight parameters. System or subsystem transportation initially affects system LCC in the Production & Deployment Phase, at which the acquired systems are deployed to their units.

During the sustainment phase of system life-cycle, transportability performance is one of the system attributes that affect the O&S costs. The

transportability effect during sustainment phase has two dimensions: the first dimension refers to system operating costs through energy efficiency if the system is self propelled, and deployment of the system to operational sites etc.; and the second dimension refers to system support costs through material transportation costs for system support requirements. System transportability performance requirements must be specified system ORD, and must be integrated with system maintenance concept and Integrated Logistics Support Plan (ILSP).

e. Organizational Factors

Organizational factors in supportability of the system refer to the legacy logistics infrastructure throughout all levels of the support environment in which the system is supposed to operate and be supported. Logistics infrastructure includes the procedures, processes, and people associated with logistics support as well as the physical resources such as support facilities, and equipment.

Systems' ILSP must be developed in such way that promotes efficient and effective utilization of the support infrastructure. The legacy logistics support infrastructure should be evaluated to realize improvements that enable reductions in system support costs. One area of interest that enables the PMs to reduce support costs and increase system availability without investing in additional numbers of systems or system spares (in order to meet operational readiness goals), is legacy organizational procedures for logisticss support. As stated previously, operational availability could be increased by reducing MDT, whose main elements are active maintenance time (M_t),

ADT, and LDT. ADT and LDT are directly related to organizational procedures or processes in the relevant logistics organizations. By improving those procedures and processes, one can reduce ADT and LDT for any system, and eventually increase system operational availability. For instance, changing service discipline from First In First Out (FIFO) to Shortest Path Method (SPM) in any maintenance organization can dramatically reduce average Cycle Time (CT) or Turn Around Time (TAT) for that organization.

2. Supportability Analysis Process

After briefly reviewing the factors that affect system O&S costs, it seems helpful to discuss supportability analysis which helps evaluate the system throughout its projected life. Supportability analysis is a sub-process within the systems engineering domain than rather being a separate entity in system acquisition process.

By definition, supportability analysis is an iterative process by which the logistics support necessary for the system under consideration is identified and evaluated within the concept of ILS. The objective of supportability analysis is to aid in the initial determination and establishment of supportability criteria as an input to design; aid evaluation of various design alternatives; aid in the identification, provisioning, and procurement of various elements of maintenance and support; and aid in the final assessment of system support infrastructure throughout the sustainment phase. [Ref. 18]

The supportability analysis is a continuous effort through system life. However the depth of the analysis and analysis tools vary at different stages throughout life-cycle

stages, depending upon the purpose of the analysis. Basic processes of supportability analysis are problem identification and needs analysis; selection of the analysis approach; establishing evaluation criteria; selection of appropriate analysis techniques; model-building and data collection; evaluation of alternatives using the model; and analysis of results.

The analysis tools utilized during the performance of supportability analysis are briefly mentioned in previous subsection in the context of their relevant supportability factors.

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III. COST ESTIMATION

Cost estimation can be defined as a process in which the financial resource requirements, which are required for developing, manufacturing, fielding, operating, and sustaining a system, are explored either for budgeting, programming, and funding purposes, or analysis of system effectiveness and analysis of alternative system designs. Cost estimating is a recurring activity throughout system life rather than a one-time activity during the system acquisition period, and generally the quality of the estimates increases as the program moves through the phases of system life-cycle since the level of uncertainty decreases.

The available methodologies for cost estimation are classified as the analogy approach, parametric techniques, the engineering approach, extrapolation from actuals, and the expert opinion approach; those techniques will be discussed comprehensively in the following section. Regardless of the methodology employed, there are some prerequisites in order to develop qualified cost estimates. First, all the relevant costs should be included into the cost elements of the system, which refers to completeness of the estimate. Second, the methodology employed in order to develop a cost estimate must be suitable to circumstances such as availability of data, and the purpose of the estimate etc., and must consider the differences with analogous systems' cost data in technology, and socio-economic conditions (which refers to reasonableness of the estimate). Finally, the assumptions upon which the cost estimates are based and cost

estimation documentation must be supportable by the facts, be consistent within their own context, and be valid (which refers to consistency of the estimate).

The quality of cost estimates developed for any system is very important since all the resource allocation decisions, and system effectiveness evaluations are based on those estimates; and as it was stated previously, the cost estimate for the system under consideration must be updated throughout the system life-cycle in a way that reflects future costs based on the current status of the program, and identify cost-drivers.

A. COST ESTIMATION TECHNIQUES

In this subsection, the cost estimating techniques, the relationship of those techniques to system life-cycle, and their effectiveness will be discussed. As pointed out in the previous section; the available cost estimating techniques are the analogy approach, parametric estimating, the engineering approach, extrapolation from actual, and the expert opinion approach.

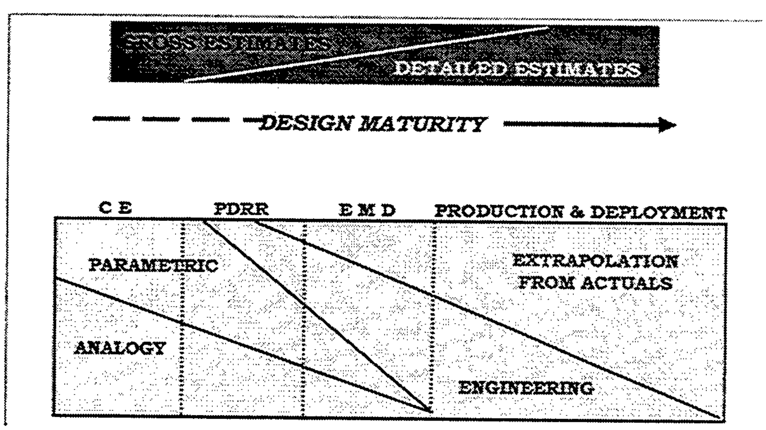

Figure 16: Cost Estimation Techniques Utilization through System Life [From Ref. 16]

All of those techniques are not mutually exclusive; they can be utilized concurrently in order to verify the cost estimate. However, there are limitations such as unavailability of data to develop detailed estimates when utilizing the engineering approach and the extrapolation from actuals technique. Figure 16 depicts the utilization of these techniques throughout system life-cycle.

Three of those techniques, the analogy approach, parametric estimating, and the expert opinion technique (which is also known as the round table technique), generate gross estimates rather than detailed estimates. The engineering approach and extrapolation from actuals generate detailed estimates for the system under consideration.

The application of the appropriate estimating technique is a very important determinant for the quality of the estimate; the appropriateness of the technique depends on the purpose of the estimate, phase of the program, and availability of data resources. The required level of effort in order to develop a cost estimate increases exponentially as the level of detail in the cost estimate increases. All of the estimating techniques, except for the expert opinion approach, utilize mostly quantitative techniques, while the expert opinion approach relies on the subjective evaluations by the experts who are asked to estimate probable costs. In essence, the analogy approach also utilizes qualitative and quantitative techniques concurrently, since adjusting data for the analogous system requires some subjectivity.

Presumably, all of those techniques originated from hardware-intensive system development efforts, but as the weapon systems get more software-intensive, i.e.

embedded weapon systems, those techniques need adjustments in ways that would reflect the inherent characteristics of software development efforts. Relative to hardware systems, software-intensive systems are more complex, non-linear in nature, and the metrics or parameters of software are abstract and harder to understand.

In the following sections, the cost estimating techniques will be discussed comprehensively.

1. Analogy Approach

The analogy approach in cost estimation utilizes the cost data of similar systems and develops a gross cost estimate for the system under consideration. The method includes a judgment process in which the similarities and differences between comparable systems, and their cost impacts upon the new system, are evaluated. Based upon the results of his/her judgment, the cost estimator develops a gross cost estimate for the new system.

As the name of the technique indicates, the comparable systems are not identical, rather they are similar and therefore the application of the method requires some adjustments to account for differences in technology, system architecture, production methodology, technical performance variances and capabilities, and programmatic differences such as acquisition schedule, acquisition strategy, and socio-economic conditions.

Since this method requires subjective evaluations by the cost estimator, the level of uncertainty in the estimation is very high, and the quality of the estimate is highly sensitive to the experience of the cost estimator. In order to make the judgment process more reliable, the cost estimator consults with the engineers, logisticians, and other technical experts related to systems under consideration, and develops costs estimates based upon feedback from those functional areas of expertise.

Although the analogy method includes a high level of uncertainty, this method is useful during the early phases of the system acquisition process because of the unavailability of cost behavior data to develop more accurate estimates for the new system and thus assess its practicality.

2. Parametric Approach

Parametric cost estimating is a quantitative technique that uses statistical analysis methods in order to develop a cost estimate, and develops Cost Estimating Relationships (CER) using system physical or performance characteristics, i.e. system parameters. The basic assumptions of parametric estimating are: the cost is a function of system parameters, parameters are statistically independent variables, meaningful CERs can be developed using a cost and performance database comprised of similar systems, and the historic cost relationships derived from the cost performance database is valid for the new system.

In this technique, estimating relationships using system parameters such as weight, power, speed, frequency, and thrust etc. are used to predict system cost;and the regression analysis is the fundamental tool for developing CERs. The parametric estimation procedure consists of statistically fitting a line or function to a set of related historical data and then substituting the appropriate parameter of the new system into the resulting equation. The data used to derive the CERs should be adjusted against inflationary effects, other programmatic circumstances, and technological differences.

This method is generally used during system life-cycle phases prior to FRP; it is used when system performance parameters are mature, but the design parameters are not.

3. Engineering Approach

The engineering method, which is also known as the "bottom-up" method, is the most detailed and time-consuming of all the cost estimating methodologies. However, the increased expense of this method is generally not justified by its significantly greater accuracy, since individual errors in each Work Breakdown Structure (WBS) element tend to produce a large error in the overall cost estimate.

Basically, in this method, the cost figures are developed for the lowest level WBS elements, i.e. component level, from either actuals or by utilizing the estimation methods described in this section, and then the figures are summed up through the upper levels of the WBS in order to develop a system-level cost estimate. The adjustments are made for

non-material cost elements such as quality assurance, system integration, and program management efforts, based on historical cost factors for the similar programs.

Although it seems very consistent and objective, this method also has some level of uncertainty just like all of the estimating methods. The uncertainty results either from individual errors made at lower levels of WBS, as stated previously, or from unprecedentedly complex system integration efforts. System integration requires much more than merely putting the components or subsystems together to form a system. This method can be utilized after the system design is stabilized and the system WBS is clearly defined.

4. Extrapolation Approach

The Extrapolation technique uses the actual costs incurred during the previous production of the same system, i.e. prototype recurring costs or low-rate initial production recurring costs.

This method seems the most reliable cost estimation method for the system under consideration; however the data required for extrapolation is available only after LRIP of the system is performed, and requires some adjustment for different kinds of reasons. First of all, the system may require some modifications prior to FRP commencement due to operational test results, so the system may differ from prototypes or LRIP models in some aspects, and the cost impact of this difference might be greater than anticipated.

Therefore, the cost analyst should consider those differences and their cost impacts on stabilized models.

The other need for adjustment stems from production methodology differences between prototype or LRIP and FRP. Prototype production is rather a craft type production in which the higher level engineers or technicians are deeply involved in manufacturing process. Production methodologies and material costs are not yet optimized and the capitalization of the learning curve effect is not possible since there are no standard procedures. The quantities to be manufactured are so small that the average unit cost for prototypes or LRIP units are substantially higher than the average unit costs for future FRP units. On the other hand, during FRP, the production process is more like an assembly line in which the optimal levels of employee mix have been established, manufacturing methodologies are standardized, and optimal material supply systems have been developed. The end result of those improvements is substantially lower average unit costs through minimization of labor, material, and overhead costs relative to prototypes or LRIP units. The cost analyst should also consider those cost impacts in performing extrapolation for the future cost estimates.

5. Expert Opinion Approach

Expert opinion, which is also known as "round table" method, involves qualitative approaches to the estimation of costs related to the system under consideration. This method heavily relies on the subjective evaluations of domain experts, such as software engineers, logisticians, or mechanical engineers etc.; is

generally employed when developing cost estimates for systems or research projects which are very innovative, and there is no previously developed analogous system or similar research. Especially in the software domain, where technological innovation rates are very high, and the products are inherently complex, abstract, and unique, the evaluations of software experts are the foundation of cost estimating.

Since the method involves the subjective evaluations of the domain experts, the level of uncertainty is very high. The critical factor that derives the reliability of the estimate is choosing credible, experienced, and knowledgeable experts. The other appropriate measures for increasing the reliability of the estimates are consulting with more than one expert in any domain, encouraging the experts to develop weighing scales for the cost-drivers, and asking for ranges with estimated variation rather than point estimates.

B. COST ESTIMATION TOOLS

This section of the study will discuss the auxiliary techniques and methods which enable cost analysts to enhance robustness, reliability and accuracy of their cost estimates which were developed by utilizing any or a combination of the basic methods described in the preceding section. The author of this thesis prefers to classify those methods under the domain of cost estimation tools, since those methods metaphorically can be found in the toolbox of the cost analyst and are independent of the basic technique or techniques.

Those tools are: **learning curve analysis**, which is mostly relevant to recurring production costs; **cost uncertainty analysis**, which is related to risks involved in the developed cost figures; and **sensitivity analysis**, which is related to trade-off issues, "what if" questions for the system's technical, programmatic parameters, and their cost impacts on LCC under different scenarios. In the following subsections, those tools will be discussed in detail.

1. Learning Curve Analysis

Learning curves describe the empirical relationships between output quantities and certain input quantities, especially in recurring production activities where the learning inducement improvement is present [Ref. 20]. A learning curve depicts the concept that the cumulative average unit cost, or unit cost of the item manufactured, decreases in a systematic pattern as the quantity of production increases. The relationship between the production quantity and the cost of the systems produced is formulated such that the unit cost or cumulative average cost of the system decreases by a common percentage as the quantity produced doubles. There are many models developed for application of this concept, but the most popular one is the log-linear model, which is depicted in the following paragraph. In the formula; Y_N represents the cost of the N-th unit, A represents the theoretical cost of the 1^{st} unit, and B represents the slope coefficient of the learning curve.

$$Y_N = AN^B$$

The slope coefficient of the learning curve can be calculated by following equation.

$$B = \frac{\ln(LEARNING\_SLOPE)}{\ln 2}$$

The learning curve theory is based on a simple principle of human nature: people learn from experience, and the learning phenomenon increases people's productivity and efficiency. There are two factors that constitute learning phenomenon in the production environment: one being the learning in literal sense on the part of labor force, and the other being enterprise-wide business process improvements derived from lessons learned from practice.

The cost impact of learning curve theory during system life cycle can be very substantial on system production costs, especially when a large number of systems are required to be manufactured; this cost impact should be factored into the production cost projections for the systems under consideration. On the other hand, there is a negative relationship between the employee turnover rate and achieved learning within any organization, therefore when factoring the cost impact of the learning phenomenon into system production cost estimates, the cost analyst should make adjustments for employee turnover rate.

The learning curve theory may have also have an impact on system LCC during the sustainment phase in which system maintenance actions are performed. However, in general practice, the system maintenance costs are estimated by the mean maintenance

time parameter, which is developed by statistical experimentation methods and therefore the learning phenomenon is indirectly factored into calculation of mean maintenance times.

As an extension to the learning curve model, the log-linear model described above, the rate adjustment model is also used in industry. The rate adjustment model basically assumes that in addition to learning rate, the production rate, which defines the quantity to be produced in certain period, also affects production costs systematically. The relationship formulated at following formula in which the "Q" represents the production rate, "C" represents the rate coefficient, and the other variables representing the same values in the learning curve formula.

$$Y_N = AN^B Q^C$$

Similar to the learning curve theory, the rate coefficient, C, can be calculated by the following equation.

$$C = \frac{\ln(RATE\_SLOPE)}{\ln 2}$$

2. Cost Uncertainty Analysis

In general, cost uncertainty analysis is the process of quantifying the cost impacts of the uncertainties associated with cost estimation methodologies and the cost data utilized in developing cost estimates. These uncertainties in cost estimation arise either from inherent uncertainties in the data collection and estimating methodologies involved

in the estimating process, or from uncertainties in program and system parameters. Economic uncertainties that influence the cost of technology, the labor force, geopolitical policies, the validity of the assumptions made by the cost analysts such as the amount of software reuse and integration efforts, further contribute to the cost uncertainty inherent in system development efforts. The uncertainties in program and system technical parameters and their cost impacts can be also assessed through sensitivity analysis, which will be discussed in the following subsection. [Ref. 21]

Because of the aforementioned uncertainties, the realization the probability of a point estimate developed through the cost estimation process is literally almost zero. Therefore the cost figures are stated in the form of statistical distribution functions based on the statistical analysis of the available cost data. For instance, the cost figures developed through regression analysis application are used in the form of a normal distribution function with a standard deviation rather than a point estimate, such as expected regression value.

As discussed previously, the system cost breakdown is comprised of many cost elements and sub elements such as manufacturing costs and its sub-elements etc., and the overall system cost is estimated through the summation process of those relevant cost elements. This summation process affects cost uncertainty substantially and in such a way that the variability decreases and the overall cost estimate approaches a normal distribution function regardless of different distribution functions used in the sub-element

cost ranges. This tendency towards normal distribution is called "central limit theorem" in statistical science [Ref. 21].

Simulation is the primary method for conducting uncertainty analysis, and the Monte Carlo simulation technique is a successful tool used to develop cost figures based on defined uncertainty parameters. Basically, the Monte Carlo simulation produces random numbers according to the statistical distribution functions defined in the system cost elements, repeats this process until the desired number of trials is achieved, and gives the expected value with statistical central tendency metrics such as standard deviation, mean, mode, and frequency.

The benefits of cost uncertainty analysis for the decision-makers can be classified into three categories: establishing cost and schedule risk baseline, determining cost reserve, and conducting risk reduction trade-off analyses.

Baseline cost and schedule probability distributions for a given system configuration, acquisition strategy, and cost-schedule estimation approach provides decision-makers visibility into potentially high-payoff areas for risk reduction initiatives, and an assessment of the likelihood of achieving the budgeted cost for a given schedule. Cost uncertainty analysis also provides a basis for determining cost reserve as a function of the uncertainties specific to a system through an assessment of maximum cost magnitude and its likelihood. Besides those benefits, the cost uncertainty analysis can be

conducted in order to assess the effectiveness of alternative risk reduction strategies for reducing system cost and schedule risks and their respective payoffs.

3. Sensitivity Analysis

In general, sensitivity analysis is the process by which the cost impacts or marginal effects of variations in the program input parameters such as system technical performance and supportability requirements, or in the program schedule, are examined. Sensitivity analysis is also known as "what if" analysis. In order to conduct meaningful sensitivity analysis, sound relationships between system or program parameters and system LCC must be developed as a prerequisite.

Sensitivity analysis differs from cost uncertainty analysis in such a way that cost uncertainty analysis is performed within the given program and system parameters, whereas the sensitivity analysis is performed through playing with given input parameters of the system or program. Basically, sensitivity analysis is conducted by changing one of the input values of the program or system while holding other parameters constant, and assessing the cost impact of this change on the LCC of the system. However, those two methods, uncertainty analysis and sensitivity analysis, are complements to each other rather than alternatives.

Primarily, sensitivity analysis is conducted during system development efforts in order to perform life-cycle cost-oriented design trade-offs, which aim to optimize system design in terms of both performance effectiveness and cost efficiency.

C. COST ESTIMATING PROCESS

The generic cost estimation process includes these activities: definition and planning, data collection and analysis, estimate formation, review and presentation, and developing final cost estimate and documentation. [Ref. 22]

1. Definition and Planning Activity

Definition and planning activity includes the identification of the cost estimating purpose; definition of system parameters, ground rules, and assumptions; selecting appropriate estimating approach; and formation of the cost estimating team.

Identification of the purpose of the cost estimate directly affects the scope, level of detail of the estimate, selection of the estimating technique, and the type of cost estimation documentation required. As stated previously, system cost estimation studies are conducted for two main reasons: budget formulation, i.e. developing baseline for resource allocation decisions, and comparative studies such as system effectiveness evaluations and evaluation of design alternatives etc.

Definition of system parameters, ground rules, and cost assumptions provides a basis on which the system cost will be estimated. System parameters include the physical or performance characteristics of the system, whereas ground rules and assumptions include acquisition strategy, program schedule, statements and conditions that affect or are assumed to affect system LCC, and assumptions for the WBS elements.

As stated before, the quality of the estimate is directly affected by the appropriateness of the estimating approach utilized, and the selection of estimating approach depends upon the purpose of estimate, availability of data, and time. In definition and planning activity, the cost analyst tries to choose the best approach depending upon the constraints mentioned previously.

The cost estimating process requires teamwork rather than one-man activity; therefore the cost analyst should determine the appropriate mix of experts, depending on selected estimating approach, and Cost Analysis Requirements Description (CARD) document, which is developed during description of system parameters, ground rules, and assumptions. The guiding principle in building a cost analysis team should be the IPPD concept, discussed in the previous chapter.

2. Data Collection and Analysis

In this phase of the cost estimation effort, the data required for the cost estimate is collected from alternative data resources such as Defense Acquisition Executive Summary (DAES) reports, Selected Acquisition Reports (SAR), price indexes, or cost factors handbooks etc. The type of required data depends on the selected estimation approach; however it includes not only cost data, but technical and programmatic data for the system as well.

The collected data are generally in raw form and require some adjustment process, which is also known as the normalization process. In the normalization process,

inflationary and other programmatic effects such as quantity, technology changes, or differences in data collection methods are stripped off in order to make the data elements compatible with each other. For instance, all then year or different constant years cost figures are converted to common constant year figures. Then the normalized data is analyzed for identification of statistical properties.

3. Estimate Formation

Estimate formation is the process by which the chosen estimating approach is applied and the cost model for the system is developed according to the assumptions and ground rules determined in the definition and planning phase. The normalized data and the results of data analysis in the previous phase are used to develop CERs, cost factors, analogies, and learning curves, and then those relationships are applied to the program under consideration.

As the final step in the estimate formation phase, the developed cost figures are spreaded fiscally throughout the program and converted to then year cost magnitudes if the purpose of the estimate is budget formulation. However, if the purpose of estimate is to conduct comparative studies, such as effectiveness evaluation or evaluation of different design approaches, then the most useful method is to convert the cost figures into present value using appropriate discount rates.

4. Review

In the review phase: the robustness, completeness, reasonableness, and realism of the estimate are tested through sensitivity and uncertainty analyses. As was mentioned above, the sensitivity analysis is conducted through playing with cost model input parameters such as system parameters or other programmatic parameters. In uncertainty analysis, both the program cost and schedule risks within the program and the system parameters are assessed; and the effectiveness of alternative cost and schedule risk reduction initiatives are evaluated. There is a feedback loop between the definition, planning, and review phases. The feedback enables cost analysts to test different system and program parameters through sensitivity analysis, and the cost and schedule probability assumptions through uncertainty analysis.

5. Documentation

Documentation refers to consistency of a cost estimate, and is rather a continuous activity throughout the estimation process although it is discussed here as if it were the last step in the estimation process.

As it is evident from the preceding discussions throughout the chapter, the cost analysis process requires judgments and assumptions by the cost analysts on the team. All those judgments, assumptions, and their rationale must be supported by factual information throughout documentation activities.

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IV. ATACMS IA LCC COST ESTIMATION

A. SYSTEM DESCRIPTION

1. Mission

The Army Tactical Missile System (ATACMS) Block IA was developed to satisfy the Army's urgent need for a long-range weapon that operates in near all-weather, day or night conditions. The ATACMS Block IA is capable of effectively engaging high value targets at ranges well beyond the capability of cannons, rockets, and the Army ATACMS Block I missile system, and is required to be efficiently transportable with available transportation modes; air, rail, and truck. The ATACMS IA will effectively attack and defeat Surface-to-Surface Missile (SSM) units, Air Defense (AD) units, Command, Control and Communication (C3) sites, and helicopter Forward Area Rearming and Refueling Points (FARRPs) of the hostile force.

The ATACMS Block IA will be fired from a modified M270A1 Multiple Launch Rocket System (MLRS) Launcher and will be deployed within the ammunition loads of corps MLRS battalions and division artillery MLRS batteries. The corps MLRS battalions will provide fires for General Support (GS) of the corps, and GS-Reinforcing (GSR) to selected divisions. Divisional MLRS batteries with ATACMS IA will provide GS to divisional force.

2. Sub System Functional and Performance Descriptions

a. Guided Missile Launch Assembly (GMLA)

(1) Guidance and Control Section: The Guidance and Control Section is formed by Improved Missile Guidance Set (IMGS) which employs GPS corrections and provides all navigation, guidance, autopilot, and communications functions for the ATACMS IA missile. Continuous determination of position, attitude, and motion are provided by the inertial sensors, associated electronics, and software processing. Guidance and autopilot functions are provided by software processing. Furthermore, all communications, both internal and external to the missile, are provided by IMGS electronics and software processing.

(2) Payload Section: The primary function of the payload section is to carry, protect, and dispense the payload of M74 grenades whose total weight is 350 pounds. The warhead has a safe and arm fuse, and a Skin Severance System (SSS), which controls the release of M74 grenades at the programmed time. The SSS includes an arrangement of Flexible Linear Shaped Charges (FLSC), which split the payload section skin into three panels. This action opens the payload compartment, allowing the entire load of grenades to disperse over target.

Furthermore, the Payload Section has an embedded GPS antenna system, which is designed to operate in the high temperature environment involved with missile flight, and to perform in the presence of threat jammer signals.

(3) Propulsion Section: The propulsion system furnishes the energy necessary to launch the missile and sustain missile flight to meet ATACMS IA altitude and range requirements, and a Solid Rocket Motor (SRM) provides the thrust for the missile. The SRM consists of a motor case, propellant, insulation/liner, nozzle, and Igniter Arm/Fire Assembly.

(4) Control Section Assembly: The primary functions of the Control Section Assembly (CSA) are to position missile fins, provide missile flight power, and perform selected pyrotechnic functions. The CSA consists of a Control Actuation Set, pyrotechnically activated electronics and control power batteries, four fin assemblies, an electrical harness, and a machined boat-tail structure. The CSA is attached to the aft end of the SRM surrounding the motor nozzle.

(5) Enclosure Assembly and Launch Pod: The Enclosure Assembly and Launch Pod (EALP) serves as a shipping, handling, transportation container, and launch pod for one missile to be fired from a M270A1 launcher. The EALP is sealed for environmental protection, and is equipped with desiccant to control humidity within the enclosure.

b. MLRS M270A1 Launcher

MLRS M270A1 Launcher is the platform from which the ATACMS IA missiles are fired, and is capable of transporting and launching two ATACMS missiles consecutively. The M270A1 is comprised of a modified infantry fighting vehicle, and a

launcher/loader module. The tracked vehicle provides a multi-terrain capability and is the base for the M269 launcher/loader module, which houses two missile pods, each containing one missile. Electrical/electronic controlling devices are mounted in the M270 for aiming and positioning the M269 in the azimuth and elevation axis.

The M270A1 is designed for operation with a crew of three; a driver, gunner, and a chief crew. Additionally, it is equipped with an onboard Fire Control System (FCS) and Improved Position Determining System (IPDS). The FSC enables the crew to program fire missions while enroute to launch points, reducing mission cycle time for the system. The IPDS determines azimuth reference data and launcher position data, and information from IPDS along with targeting information are transferred to the missile during pre-launch phase.

The current M270A1 MLRS launchers, which are issued to units with deployment of ATACMS I missiles, will be utilized for ATACMS IA missiles without significant modification for MLRS launchers except interface software modification. Additionally, launcher operating and support costs of the MLRS units will not be affected by the deployment of the ATACMS IA missiles, and there will not be additional operating personnel requirements for the system, except initial orientation training of the operating personnel.

c. Support Equipment

The maintenance concept for ATACMS IA requires two levels of maintenance; namely ammunition general support level, and depot level maintenance. The required support equipments for those maintenance levels are Guided Missile Test Set at general support level and Missile Test Station Equipment (MTSE) at depot level support. In the succeeding paragraphs those support equipments will be discussed briefly.

(1) Missile Test Device (MTD): MTD is a small portable test set that can perform electronic checks to determine the serviceability of an ATACMS IA missile in its EALP while not on board a launcher without affecting the integrity of that EALP. It will be utilized at ammunition supply points and at ATACMS IA maintenance facilities.

(2) Missile Test Station Equipment Set: Missile test stations are used at Army ATACMS missile facilities to perform functional and diagnostic testing of ATACMS IA GMLAs. A missile test station has two kinds of equipment; Missile Test Station Equipment (MTSE) and Missile Test Station Augmentation Equipment (MTSAE). The MTSAE is used to perform detailed diagnostic testing of ATACMS IA Inertial Measurement Unit (IMU) and Control Section Assembly (CSA), and to print data stored in the GMTS.

d. Training Equipment

The ATACMS IA training equipment consists of a M165 Guided Missile Training Set and a Guided Missile Test Set Trainer. In the following paragraphs, those training sets will be introduced briefly.

(1) M165 Guided Missile System Training Set: The function of this training set is to support training of ATACMS Explosive Ordnance Disposal (EOD) personnel. The set provides familiarization training with the physical aspects of the missile and the location and identification of internal components. It also provides a capability for training EOD personnel to determine the GO or NO-GO status of the missile Arm/Fire and Safe/Arm Devices.

(2) Guided Missile Test Device Trainer: The Function of The Guided Missile Test Trainer is to support training of Guided Missile Test Set Operators to perform GO-NO-GO status and surveillance testing of ATACMS IA missiles. The trainer is physically the same as the ATACMS EALP except it is equipped with ballast to stimulate missile weight, a malfunction panel, and other components to provide missile malfunctions to Missile Test Device.

e. Computer Software Configuration Items

The ATACMS IA missile system's software subsystems consist of approximately 600,000 lines of code of which 200,000 lines are developmental, 370,000 lines are modified and 40,000 lines are re-use software elements. Addition to Ada

language, which is the primary software implementation language for the mission critical computer software of the system, the other languages, namely Jovial, Assembly, Fortran, and Pascal, are utilized in development and integration of ATACMS IA software. In the subsequent paragraphs, the software subsystems of the system will be discussed.

(1) Navigation and Guidance Computer Operational Flight Software (NOFS): This program is responsible for guiding and navigating the missile, and contains an executive program which performs alignment, navigation, Built In Test (BIT), auto pilot, guidance, and weapon dispense function. The guidance set software communicates with launcher to perform its functions.

(2) Navigation and Guidance Computer Inertial Program Loader Software (NIPLS): The general purpose of this program is to provide automatic control of the NOFS upon application of electronics systems power to the missile. Functions of the NIPLS include performing power-up BIT, loading flight software, transferring control to the flight software, purging classified data, and providing communications with Navigation and Guidance Computer, Inertial Sensor Computer, and the launcher.

(3) Inertial Sensor Computer Software: this software sub system is responsible for communicating with the gyros and accelerometers. The functions of this software include BIT, alignment, accelerometer correction, gyro

correction, dynamic motion compensation, coordinate transformation, attitude reference, gimbal control, and autopilot filter functions.

(4) Inertial Program Loader Software (IPLS): the functions of IPLS include performing power-up BIT, loading ISCP flight software, transferring control to flight software, and providing communications with Inertial Program Loading Software associated with Navigation and Guidance.

(5) Embedded GPS Receiver Computer Program: This computer program enables the missile to interface with GPS satellite system, and provides continuous data flow to the NOFS and ISCS.

(6) Control Actuation System Computer Program (CASCP): This program is responsible for arming Solid Rocket Motor (SRM), command destruct, enabling War Head, controlling fin actuators, BIT, umbilical break wire monitoring, and communicating with Improved Missile Guidance System.

(7) Guided Missile Test Set Software: this software resides in GMTS and performs tests on the missile that determine the missile's GO-NO-GO status.

(8) Missile Test Set Software: This computer program resides in Missile Test station equipment and performs diagnostic tests for missile at depot-level maintenance.

(9) M270A1 Launcher Software: The Launcher software is embedded in launcher's FCS and IPDS systems and enables those systems to perform their intended functions.

3. System Operational Concept

As stated previously, the ATACMS IA missile system will be deployed within the ammunition loads of corps MLRS battalions and divisional MLRS batteries, and will be fired against high value targets such as enemy Surface-to-Surface Missile Units; Command, Control and Communication sites etc. which are beyond the ranges of traditional artillery weapons.

The deployment plan of the ATACMS IA missile system was formulated to minimize the cost of fielding by fielding of the system to existing MLRS units with no additional personnel, and minimal additional training, rather than developing new units, and new Military Occupational Specialties (MOS). In this study, the numbers of fielded systems are considered cumulatively rather than on a unit-by-unit basis, because of security considerations.

The ATACMS IA missiles have four modes and states; storage, pre-launch, flight, and dispense. The EALPs will be stored at ammunition supply points, and aside from training and military exercise purposes, the missiles will be issued to MLRS units during contingency times. During storage mode, the EALPs will be stored in outside covered storage, and no major preventive maintenance will be required except annual

inspections, surveillance testing, and corrosion control activities, if required. The pre-launch mode begins when the Guided Missile Launching Assembly (GMLA) is loaded onto the M270A1 Launcher and ends with missile launch. The activities involved with this mode include movement from the launcher re-load point to the missile firing point, upload of the missile flight software, conduct of pre-launch procedures, and alignment transfer from the launcher to the ATACMS IA missile. The flight mode involves all the missile activities during time period from launching to the destination, target area. The payload of the missile is dispensed over the target area during the dispense mode.

M270A1 MLRS Launchers will be stationed at the MLRS units, and were designed to be operated by the crew of three; a driver, a gunner, and a crew chief. As stated previously, the fielding of the ATACMS IA missiles will not require additional O&S costs for the M270A1 MLRS Launchers, thus the O&S costs for the launchers are excluded in the LCC estimation for the ATACMS IA missiles. The deployment of missiles system will only require initial orientation training for the current launcher operators.

4. System Support Concept

The ATACMS IA system will utilize the standard Army support structure to the maximum extent possible and in accordance with the Integrated Logistics Support Plan for the system. The support concept for the system differentiated between the hardware sub- system support and software sub-system support. The initial spares, repair parts, and required documentation for the system and sub-systems will be provided with the

deployment of the systems. The initial spares and repair parts requirements will be calculated through operational availability target values, considering the capacities and Turn Around Times (TAT) of the relevant support facilities.

a. Hardware Support

The ATACMS IA hardware maintenance will be performed at two levels; Ammunition Supply Support, which is equialvant to General Support (GS) and Depot Level Maintenance (D). The peculiar maintenance and support activities for system hardware elements will be discussed briefly. The values of supportability performance parameters, such as MTBF, MTBM, Mean Maintenance Time, and maintenance material and personnel costs will be provided in the CASA model inputs.

(1) Guided Missile Launch Assembly (GMLA): GS maintenance support will be performed by the Support Maintenance Company utilizing 55 and 27 series of MOS personnel. Support maintenance personnel (MOS 55) will replace desiccant, spot point, and perform limited repair of damaged external structural items, covers, and panels. Support personnel (MOS 27) will check a sample of missiles annually for GO or NO-GO status utilizing the MTD. GS maintenance of the GMLA will be limited to evaluation of missile components utilizing BIT capability with the MTD and examination of the GMLA for evidence of moisture and serviceability. The unserviceable GMLAs will be evacuated to depot and will be repaired at depot utilizing existing depot plant equipment, which has the capability to fault isolate to the Printed Wired Assembly (PWA) level. Repair of the missiles will be accomplished by replacement of major

assemblies, subassemblies, and/or components of subassemblies. In addition to those unscheduled repair activities, the fielded missiles will be exposed to scheduled periodic inspection, test and repair if required at depot level, as part of the missile surveillance plan. Spares/repair parts of the GMLA will be stocked at depot level. Unit level spares/repair part for GS maintenance activities described above will be stocked in Ammunition Support Companies.

(2) Missile Test Device (MTD): GS maintenance of the MTD will be performed by the MOS 27 personnel assigned to the Ammunition Support Companies. The Operator utilizing the self-test capability of the MTD will fault-isolate to the sub assembly and/or components of subassembly. Repair of the MTD will be performed by replacement of the unserviceable item. The unserviceable items will be repaired at depot level. Additionally, the MTD will be calibrated within a scheduled time period.

(3) Training Equipment: The GS level support of the training equipment will be performed by utilizing MOS 55 personnel assigned to the ammunition support companies, and most of the maintenance function of this equipment will be performed at that level. The depot level support will only be limited to major overhauls and modifications if required.

b. Software Support

The Post Deployment Software Support (PDSS) of ATACMS IA system will be performed by the ARMY Software Support Center at depot level. The PDSS metrics will be provided in CASA model inputs section.

B. COST ESTIMATION METHODOLOGY

In order to develop the LCC cost estimate and to conduct cost risk (uncertainty) and cost sensitivity analyses of the ATACMS IA missile system, the Cost Analysis Strategy Assessment (CASA) Version 2000c Decision Support System (DSS) will be utilized.

CASA was developed by the US Army Materiel Command Logistics Support Activity (USAMC LOGSA), and designed to provide support in the decision-making process for program managers assigned to materiel systems acquisition programs. Despite numerous LCC estimation software models being available in market place, only a few have capabilities to perform supportability, operational availability, and cost uncertainty-related analyses that help program managers address CAIV issues and optimize system design during system development stages. However, the CASA model is ideal for conducting such trade-off and sensitivity analyses as well as cost risk (uncertainty) analyses. The CASA model addresses the LCC of the objective system including RDT&E, EMD and Production, the learning and production rate curves, and the entire operational life during which the system is supported in the field. Virtually, every

cost associated with the system is covered by CASA, whether one-time, recurring, or annual.

The CASA model utilizes a Monte Carlo simulation technique in order to simulate system, and/or subsystem failures; elapsed maintenance times, turn around times, logistics delay times, and cost distribution functions, etc. However, the CASA model has only four kinds of statistical distribution functions in its library; constant, uniform, triangular, and normal distributions. The exponential, Poisson, and other useful statistical distribution functions are excluded; this can be regarded as one of the drawbacks of the model. However, if large numbers of systems, or subsystems are considered in the LCC estimation and analysis, and the estimation process involves a summation of different statistical distributions; the summation process results tend to approach a normal distribution due to the Central Limit Theorem discussed previously, and the drawbacks of the model are off-set.

The CASA model has the inherent capability to consider and evaluate reliability growth or degradation of system or sub-systems, and their impact on system LCC, if applicable. This capability of the model enables the PMO to effectively model the "bathtub" behavior of system hardware components' failure rates, and conduct reliability trade-off analyses for the specified system.

For software development and PDSS activity costs, the CASA model utilizes a modified version of Constructive Cost Model (CoCoMo) as the software effort estimating methodology. The modified CoCoMo model utilizes lines of source code and other

adjustment factors such as program complexity, language level, and diversity as inputs and turns them into required man-months of efforts.

Additionally, the CASA model has capabilities that enable the PM to calculate spares requirements for the desired service levels for each maintenance echelon, and evaluate the operational availability of the system. The operational availability module of the CASA utilizes two different approaches for operational availability assessments. The operational availability optimization method determines the maximum operational availability of the system within given constraints and adjusts the spares layout to achieve the maximum feasible operational availability. The other method, which is called target value method, enables the analyst to asses the spares requirements within the given support structure in order to realize the target operational availability value for the system.

The CASA model performs the LCC estimation of the system under consideration through a summation process with approximately 82 algorithms. The model has 192 variables, most of which are optional inputs that a cost analyst can tailor to the specific needs of the program. However, the CASA model does not have the capability to develop Cost Estimation Relationships (CER) utilizing comparable system cost data, rather it requires the analysts to develop CERs utilizing regression techniques first, estimate expected cost figures' distributions for sub-systems, and plug those numbers into the model. If the CASA model had been designed to have a regression module, it would have been a very robust tool for the analysts. In this thesis; the cost elements such as

RDT&E costs, base unit production costs, learning and production rates have been either derived from ATACMS IA CARD, Selected Acquisition Reports (SAR), or assumed by the author utilizing ATACMS I cost data, since developing and validating those kind of CERs is beyond the scope of the thesis.

C. ESTIMATION ASSUMPTIONS AND CASA MODEL INPUTS

1. Estimation Assumptions

First, all the cost figures in the LCC development model are fictitious; they are generated by guidance from ATACMS IA CARD document and based on reasonable judgments by the author. Since, one of the objectives of the thesis is to explore the effects of system performance parameters such as MTBF,and MTTR on system LCC and operational availability, the objective will be realized regardless of the fictitiousness of cost figures.

As stated in previous sections, all the costs, except launcher operator initial orientation training costs, associated with M270A1 Launcher are ignored since the deployment of the missile system will not incur additional costs associated with launcher. The only additional cost will be modification of launcher software modules, and the costs associated with launcher software modification efforts are included in initial software development costs.

Although the total number of acquired systems and fielding schedule are derived from the actual acquisition schedule for the program, the numbers of General Support

units and Depots are fictitious. It is assumed that there are 10 General Support locations, each of which supports 80 missiles, and 2 Depot facilities, each of which supports 380 units. The production and deployment schedules are provided in model inputs.

Since the ATAMS IA is a missile, and required to be mission ready at all times during deployment, it is assumed that the operations would be 24 hours per day, even if the missile were in a storage mode. In addition, it is assumed that the operator-required portion of this time is 0, since there are no operators associated with the missile itself. The operators are associated with MLRS launchers.

The slope of the learning curve and slope of the production rate associated with ATACMS IA production are assumed to be .90 and .95, respectively. In sensitivity analysis, the rate changes and their prospective effects on LCC will be evaluated separately.

2. CASA Model Inputs

The CASA Model inputs are provided in Appendix A.

D. CASA RESULTS AND ANALYSIS

1. LCC Cost Estimation Results

In this subsection, the percentage distribution of the LCC major elements of missile system, which are RDT&E, Acquisition, and O&S costs are discussed. As

depicted in the Figure 17, the LCC major elements are distributed as 15%, 44%, and 41% for RDT&E, Acquisition, and O&S costs, respectively.

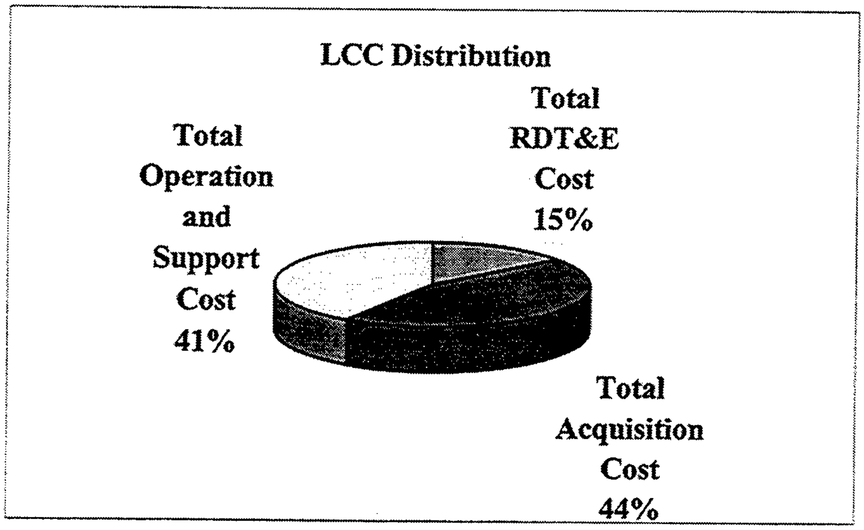

Figure 17: ATACMS IA LCC Distribution **[Source Data: Appendix B]**

As discussed previously; the RDT&E costs cover all the efforts and cost commitments that are related to development of the system, whereas the acquisition costs cover all the cost elements that are incurred to manufacture, and to field the system with required support equipment, training equipment, documentation, and initial spares. Initial spare requirements are calculated through assumed confidence levels at maintenance echelons, which are 90% for General Support Level and 95% for depot level. Additionally, the acquisition costs include the initial software development and initial training costs. The interesting thing in distribution of Acquisition cost elements into lower level categories is that initial software development efforts constitute a significant portion of the system acquisition costs, which is approximately 36% of total acquisition

costs despite conservative assumptions being made for software development efforts. As stated in CASA inputs, the initial training requirements are classified as operator orientation, GS personnel training, and Depot personnel training. O&S costs cover all the efforts and cost commitments in order to sustain the system in the field, including the software maintenance, recurring training, and recurring documentation revision costs.

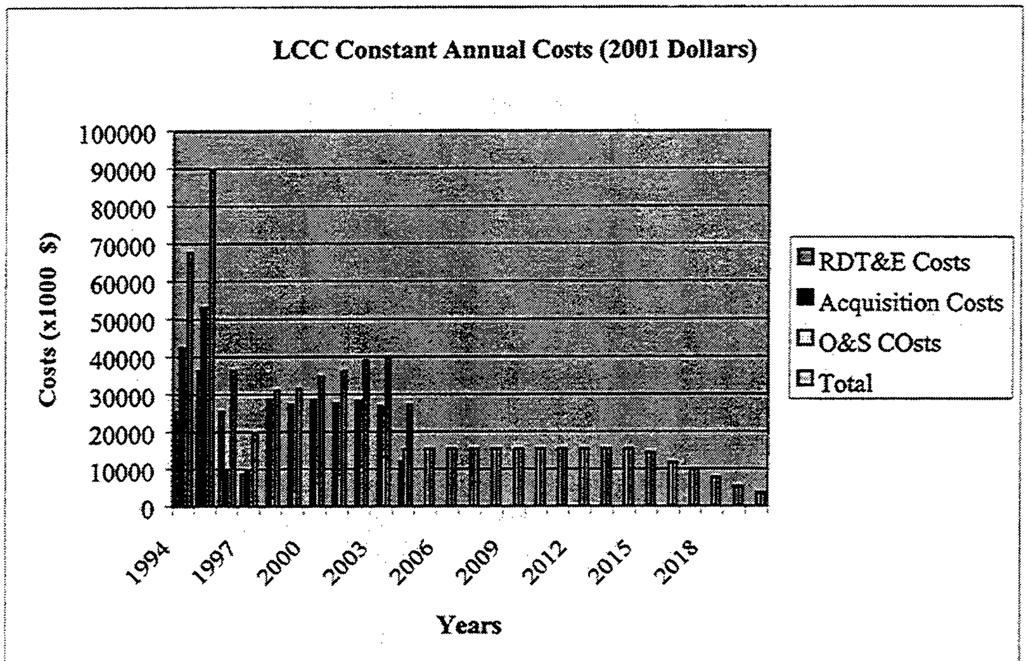

Figure 18: ATACMS IA Annual Cost Outlay in Constant 2001 Dollars [Source Data: Appendix B]

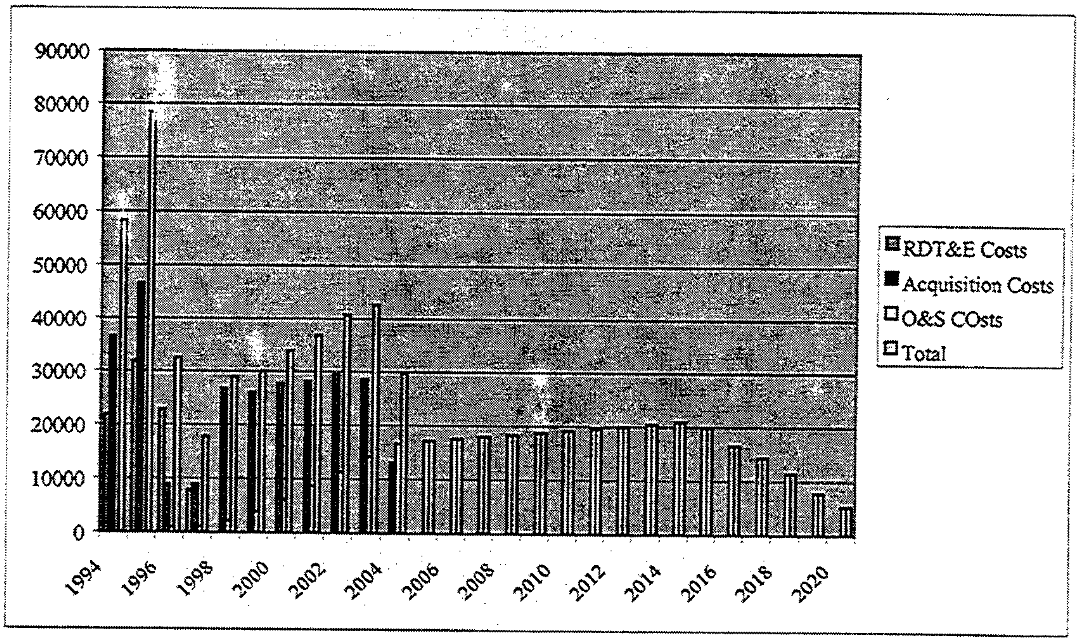

Figure 19: ATACMS IA Inflated Annual Cost Outlays **[Source Data: Appendix B]**

The detailed figures for the CASA model LCC estimation for ATACMS IA are provided in Appendix B.

2. Sensitivity Analysis

In order to evaluate the marginal effects of system cost drivers and system supportability performance parameters on system LCC and operational availability, eight types of sensitivity analysis will be conducted. These evaluations will enable the decision-makers in system acquisition and support environments to make informed decisions on alternate system configurations, acquisition strategy and schedule, and structuring the system support environment.

First five of these analyses, which are MTBF, MTTR, Unit Cost, Turn-Over Rate, and Spares TAT sensitivity analyses, are conducted to evaluate their marginal effects on

estimated LCC for the system. The following two analyses, which are Learning and Production Rate Curve sensitivity analyses, are performed to evaluate the changes in the system acquisition costs when the assumed learning and production rate slopes are changed. The author of the thesis preferred to perform sensitivity analyses for the learning and production rate slopes against the system acquisition costs rather than system LCC, since both of the cost-drivers are related to system production specifically. The last sensitivity analysis, which is operational availability sensitivity analyses, is conducted to evaluate the effects of MTBF, Spares Confidence Levels (CL), and System-Level Maintenance Elapsed Time (MET) on system operational availability. System-Level MET consists of system active maintenance time, administrative delay time, and logistics delay time for system maintenance activities. System active maintenance time, that is a weighted mean value of MTTRs of the system for corrective and preventive maintenance actions, is primarily a system design decision; but the other ingredients of MET, which are administrative delay time and logistics delay times that includes transportation of the system to applicable maintenance echelon, are related to the effectiveness and efficiency of the system support environment. However, during the system design period, the system developers can perform an effective supportability analysis for the conceived system design that enables the system to exploit the current logistics environment in most efficient and effective way.

In the following sub subsections, the results of those sensitivity analyses are discussed. The data related to these sensitivity analyses are provided in Appendix C.

a. *MTBF Sensitivity Analysis*

As discussed in the previous sections, the MTBF performance parameter denotes the time period in which system and its sub-systems or components functions in their intended ways without a failure. The decrease in MTBF of the system or its components affects systems LCC through an increased quantity of spare parts requirement at given confidence levels, increased amount of maintenance work required, and increased quantity of support equipment requirements and utilization.

As seen in Figure 20, the relationship between MTBF and system LCC is negative in nature; the increase in MTBF decreases system LCC or vice verse. However, if the system design and technology is the state-of-the-art-of available technology, then it generally requires investment in research and development activities to increase the MTBFs of the system and its subsystems or components. This requirement for pushing the edge of technology may increase system acquisition costs.

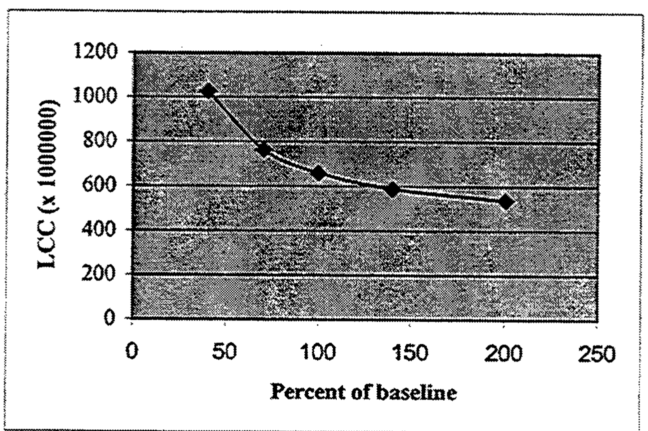

Figure 20: ATACMS IA LCC Sensitivity to MTBF [Source Data: Appendix C]

As is clear from the Figure 20, the marginal benefits, in terms of system LCC reductions, of the improvements in MTBF decreases as the level of improvement increases. For example; increasing the MTBF from its 70% to the current level reduced the system LCC by $105,000,000 which means that the average LCC savings is $3,500,000 per one percent improvement in MTBF, whereas increasing the baseline MTBF to its 140% value promises LCC savings about $70,000,000 which translates $1,750,000 saving per one percent of improvement on average. This behavior of the curve obeys the general economics principle of decreasing marginal benefits, and may provide guidance to the decision-makers in allocating resources for RDT&E activities and system reliability improvement programs.

b. MTTR Sensitivity Analysis

MTTR refers to maintainability of the system, sub-systems and their components. MTTR affects system LCC costs through system maintenance labor costs. As it is evident from the Figure 21; there is positive relationship between system or subsystem MTTR values and the system LCC, which states that as the MTTR values are increases, the system LCC cost increases proportionately.

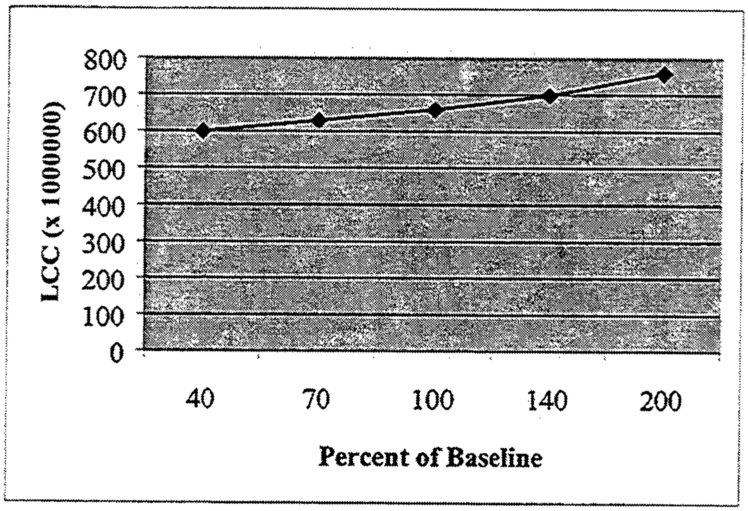

Figure 21: ATACMS IA LCC Sensitivity to MTTR [Source Data: Appendix C]

As depicted in the Figure 21, the sensitivity of LCC to MTTR values of the system and sub-systems or their components is calculated approximately as $100,000 per one percent change in the baseline values.

c. *Spares Unit Cost Sensitivity Analysis*

Spares unit cost affects LCC through both acquisition costs and O&S costs. The sensitivity analysis conducted to assess the effects of probable escalation rates for unit cost of spares and provide an enabling tool for the negotiations with contractors for either system acquisition, warranty discussions, or different types of system support agreements.

As pointed out in the Figure 22, there is a positive relationship between the spares unit costs and the system LCC; the marginal effect of 1% increase on spare unit costs is approximately $160,000 on the system LCC. The sensitivity chart reflects the

average changes on spares baseline cost figures rather than an item-by-item basis. In order to evaluate the changes on the baseline unit cost figures for each spare item more specifically, a sensitivity analysis on item-by-item basis should be conducted. However, the author did not perform that kind of analysis, because of space limitations.

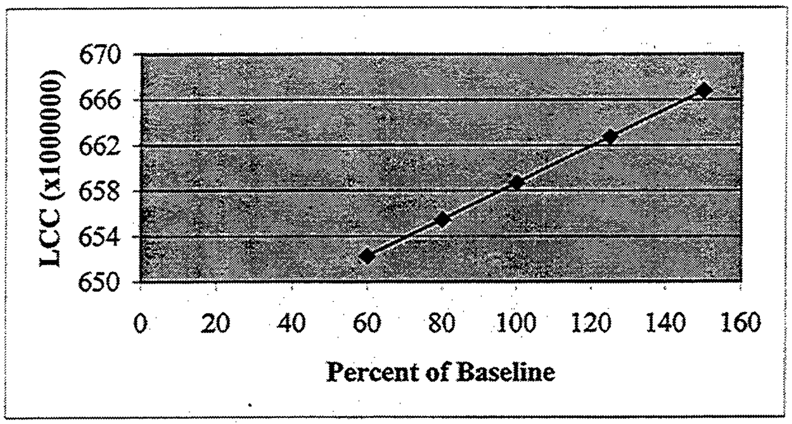

Figure 22: ATACMS IA LCC Sensitivity to Spares Unit Cost [Source Data: Appendix C]

d. *Turn Over Rate (TOR) Sensitivity Analysis*

TOR refers to the annual turn over rate of the employees associated with General Support and Depot level maintenance of the ATACMS IA missile. The launcher operator TOR is excluded from this analysis; since all the costs associated with MLRS launcher are excluded from LCC estimation and relevant analyses, as stated in the assumptions section.

The annual TOR of the maintenance and support employees affects system LCC through recurring training requirements. As the TOR increases 1% of baseline value, the system LCC increases by approximately $10,000. This analysis may prove to

be a valuable tool for the PMs and support facilities managers in developing strategies and allocating resources to employ those strategies in order to increase the retention rates of employees associated with the system.

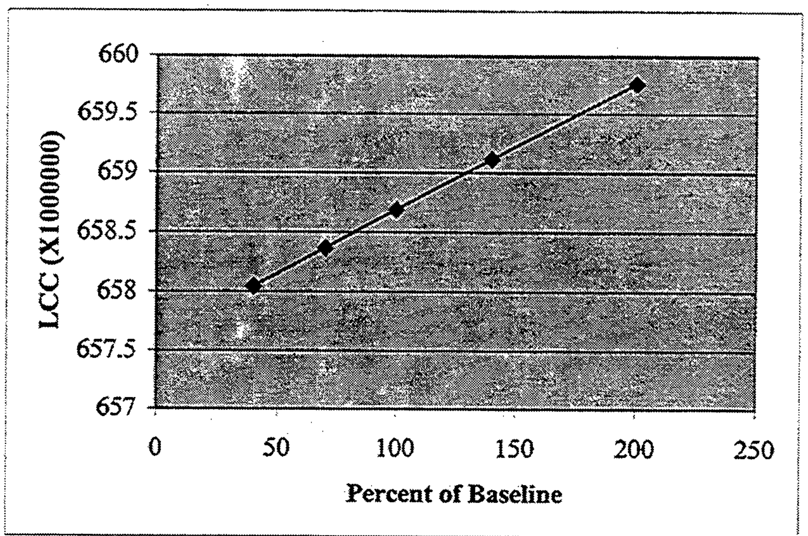

Figure 23: ATACMS IA LCC Sensitivity to Maintenance Labor TOR [Source Data: Appendix C]

e. Spares TAT Sensitivity Analysis

The spares Turn Around Time (TAT) refers to the time period that is elapsed to replace a spare unit, which is used to maintain the system, either by repairing the unserviceable one or purchasing a new spare unit. As the spares TAT increases on average, the initial spares requirements increases to meet the confidence levels throughout the maintenance echelons or vice verse. This relationship is depicted in Figure 24.

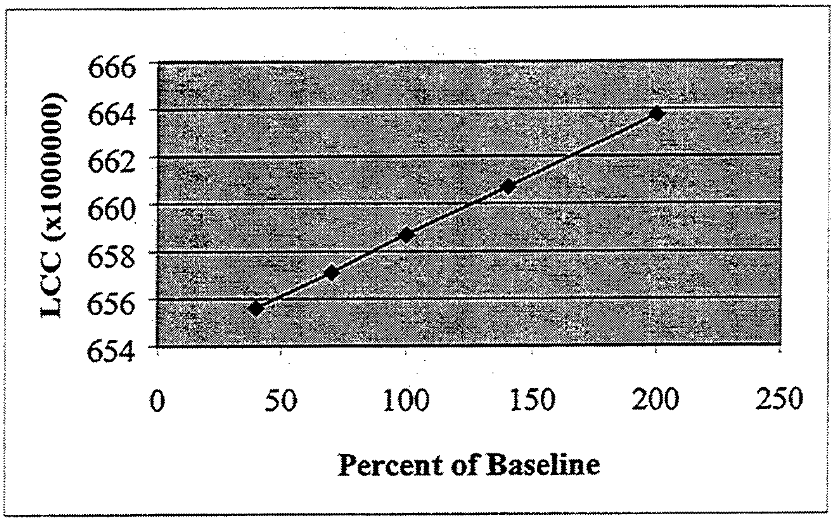

Figure 24: ATACMS IA LCC Sensitivity to Spares TAT [Source Data: Appendix C]

As the chart points out, 1% change of baseline spares TAT increases the system LCC approximately by $50,000 on average. The spares TAT is the function of spares maintainability, transportability, the efficiency of the logistics support infrastructure, and the responsiveness of the organizations associated with that spares unit. Henceforth, this analysis can be used as a decision enabler in evaluating maintainability and transportability alternatives for the system and its spares units during the system development period, and evaluating the cost and benefits of improving the efficiency of the system logistics infrastructure.

f. Learning Curve Sensitivity Analysis

Learning curves are associated with recurring production activities, therefore the sensitivity analysis is conducted to evaluate the effects of changes in assumed learning rates in system acquisition costs. As stated previously, the assumed

slope of learning curve for the system production is 90%. In the sensitivity analysis, system acquisition costs are calculated for the fractions of the baseline learning curve slope. The Figure 25 depicts the behavior of system acquisition costs for the changes of baseline learning rate.

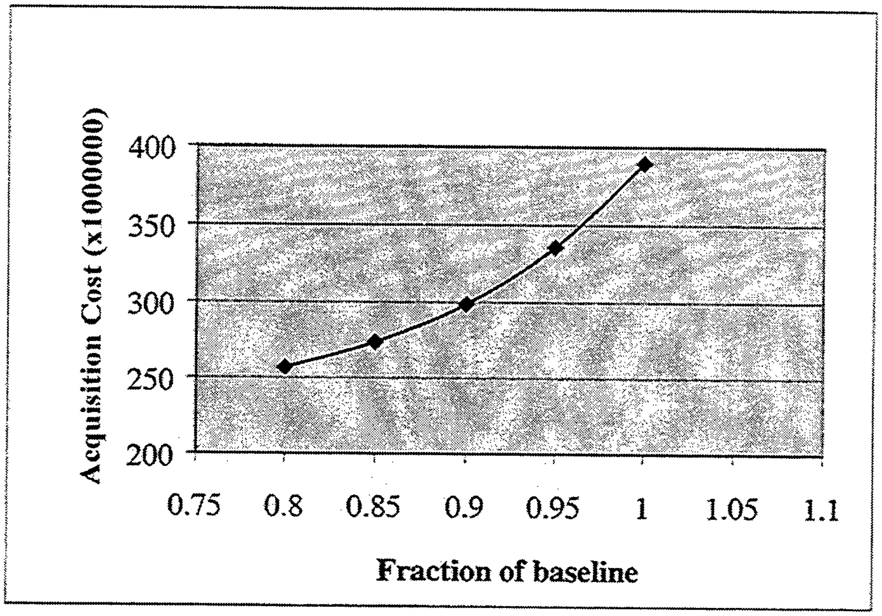

Figure 25: ATACMS IA Acquisition Cost Sensitivity to The Slope of Learning Curve [Source Data: Appendix C]

The chart shows that the acquisition costs increase at an increasing rate, as the slope of learning curve increases that is the learning rate for the system recurring production activities decreases. The learning curve analysis provides leverage for cost analysis of the contractors' production cost proposals, and enables the PMO to prepare budgeting requests and program cost estimates more effectively. Furthermore, learning curve analysis proves to be an important tool in evaluating the alternative system production schedules through assessment of their effects on learning rates.

g. *Production Rate Curve Sensitivity Analysis*

Similar to learning curves, the production rate curves are associated with system production activities; generally increased production rates decrease average cost of manufactured quantities through increased capacity utilization and reduction of production overhead costs and non-recurring costs per manufactured unit. However, this underlying assumption holds within the boundaries of sustainable production capacity utilizations, beyond those points the average unit costs tend to increase because of required cost commitments for capacity increases and higher inventory holding costs.

The slope of production rate curve refers to the degree of logarithmic relationship between production rate and system manufacturing costs; the relationship can be described such as the slope of the production rate curve gets higher value, the effects of production rate on system production costs get smaller. In order to test that assumption, and to assess the effects of different production rates on the production costs of the so-called system a sensitivity analysis is conducted for the frictions of baseline production rate slope, which is assumed to be 95%.

Figure 26 provided below depicts the changes in the system acquisition cost estimates for different values of production rate slope. As is clear from the Figure 26, the system acquisition cost estimate grows at an increasing rate as the slope of the production rate curve increases. The assessment of the effects of different production rate slopes on system acquisition costs enables the acquiring agencies to evaluate the contractor' cost proposals, develop production cost estimates for the system more

effectively, and structure the system acquisition and production schedule in a way that optimizes system production costs.

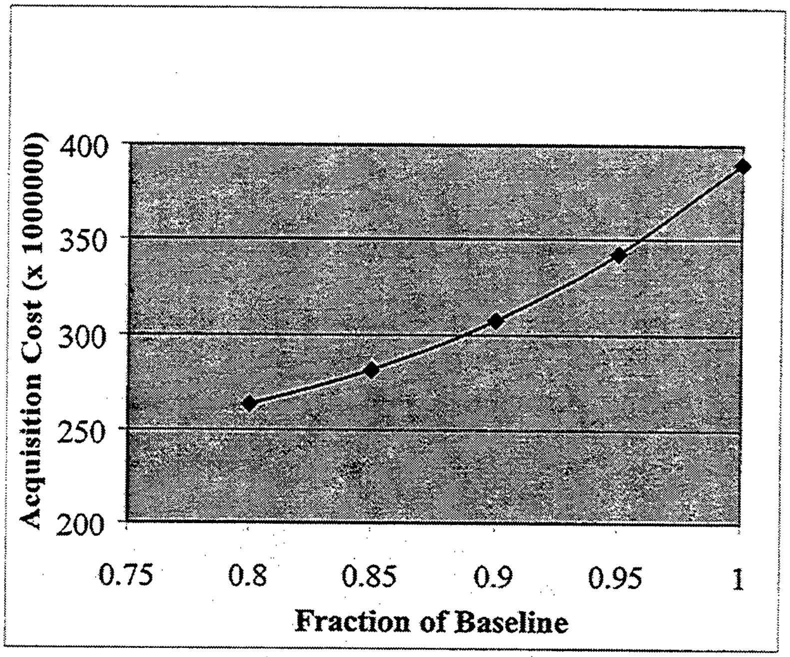

Figure 26: ATACMS IA Acquisition Cost Sensitivity to The Production Rate Slope [Source Data: Appendix C]

h. Operational Availability Sensitivity Analysis

As discussed in previous chapters, the operational availability of the system refers to the probability that the system under consideration would be available in operational status when needed during its operational life. The parameters of operational availability are system MTBF, and system level maintenance elapsed time (MET), which includes system MTTR, logistics down time that refers to the responsiveness of logistics system including transportation time, and administrative delay time that refers to responsiveness of the organization at which the system is operated. In order to assess the

marginal effects of those parameters on system operational availability, sensitivity analyses are conducted for each of those parameters. Figures 27, 28, and 29 exhibit the results of those sensitivity analyses.

Figure 27, which reflects operational availability sensitivity to the system level MTBF, depicts that the operational availability of the system increases at a decreasing rate as the MTBF increases. In other words, there is a decreasing marginal benefit, in terms of operational availability, of increasing the system level MTBFs either by pushing the edge of technology or introducing redundancy to the system at lower levels of the system hierarchy. This sensitivity analysis provides a framework for commitments for RDT&E efforts for reliability improvements, and enables the system developers to assess the effects of alternative system designs on operational availability.

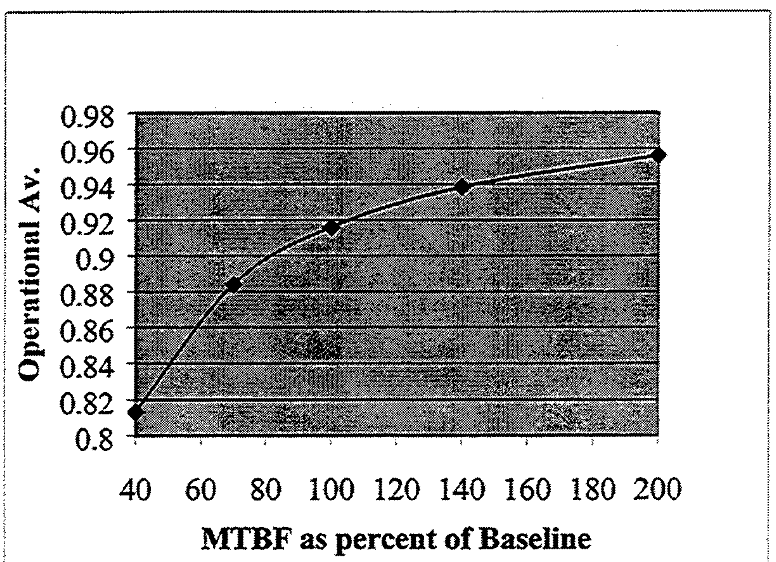

Figure 27: ATACMS IA Operational Availability Sensitivity to MTBF [Source Data: Appendix C]

Figures 28 and 29 reflect the sensitivity of operational availability to spares Confidence Levels (CL) throughout maintenance echelons and system level maintenance elapsed time that is discussed above respectively.

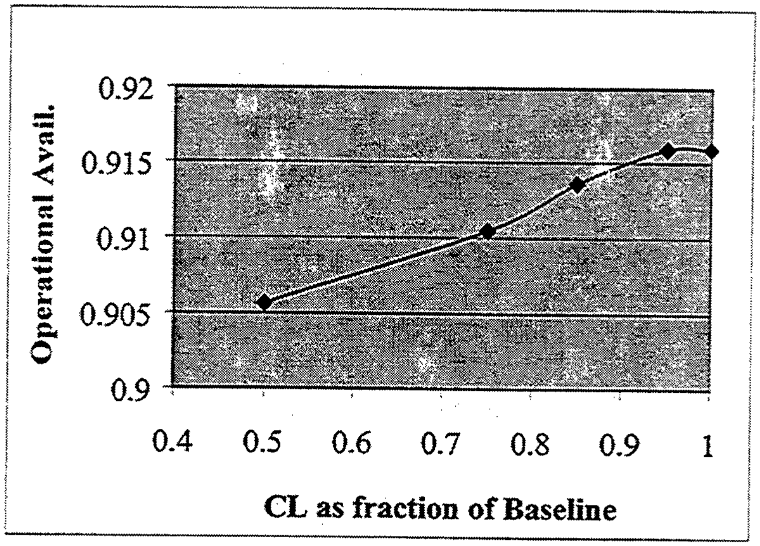

Figure 28: ATACMS IA Operational Availability Sensitivity to Spares CL [Source Data: Appendix C]

As clearly expressed in the chart, increasing spares confidence levels, which means increasing the quantity of spare parts throughout maintenance echelons, beyond 90 % of baseline values, which are 90% and 95% for General Support and Depot levels respectively, does not yield a significant increase in operational availability for the system. Furthermore, this sensitivity analysis shows that there has been only a .0102 improvement cumulatively in the operational availability of the system by increasing the confidence levels from 50% of baseline values to the 100% of baseline values. These insights from that sensitivity analysis provide valuable guidance to establish an appropriate confidence level for each of the maintenance echelons, and enables the PMO

to assess cost effectiveness of the increasing spares confidence levels or increasing spares quantities associated with the system.

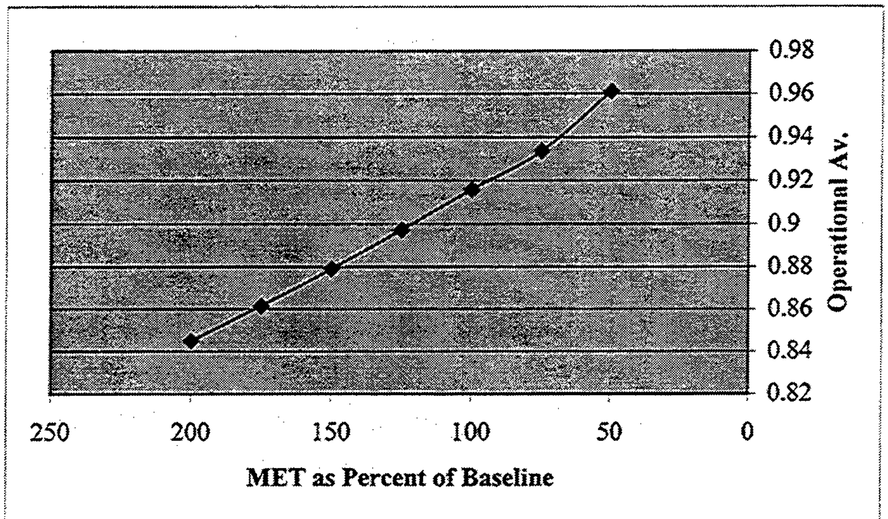

Figure 29: ATACMS IA Operational Availability Sensitivity to System Level MET [Source Data: Appendix C]

Figure 29 points out the results of the sensitivity analysis conducted to test the operational availability sensitivity to system level maintenance elapsed time, which was discussed previously. As depicted clearly in the chart, decreasing system level MET promises significant improvements in operational availability of the system. For instance, decreasing baseline value of system level MET by half (that is 50%) improves operational availability to .961 from .90. As discussed previously, the ingredients of system level MET are system level MTTR, logistics delay time, and administrative delay time; and only one of those ingredients, which is MTTR, is constrained by system design, the others are predominantly determined by the effectiveness of the logistics support infrastructure of the environment in which the system operates. Therefore, improving effectiveness of

the logistics system and eliminating non-value adding activities in the system support process, promise permanent significant improvements in the operational availability of the system.

Furthermore, when we compare the results of the MET sensitivity analysis with the results of the confidence level sensitivity analysis; it seems evident that improving the efficiency and effectiveness of logistics support organizations and processes is a more successful strategy to improve operational availability of the system than merely increasing spares confidence levels, in other words, increasing spare quantities throughout the maintenance echelons.

3. Uncertainty Analysis

In order to assess the risk associated with the assumed cost structure for the system, an uncertainty analysis is conducted utilizing a Monte Carlo simulation technique which is embedded in the CASA cost estimating and analysis model. The CASA model's risk analysis model has been limited to a maximum 200 simulation runs, therefore the ATACMS IA LCC cost risk analysis is limited to 200 simulation runs. Although 200 simulation runs is a small number to determine appropriate distribution and probabilities of the potential LCC for the system, it gives an insight into the cost risk behavior of the system. In Figures 30 and 31, the frequencies and cumulative probabilities of the potential values for system LCC are provided, respectively. The risk analysis results data is provided in Appendix D.

As discussed in Chapter II, the LCC estimation process inherently includes many uncertainties; therefore the probability of realization of a point estimate is almost zero, regardless of the estimating methodology utilized. Henceforth, it is a prudent approach to express the cost estimates with their respective probabilities or with their probability distribution type and parameters such as mean value, standard deviation, etc.

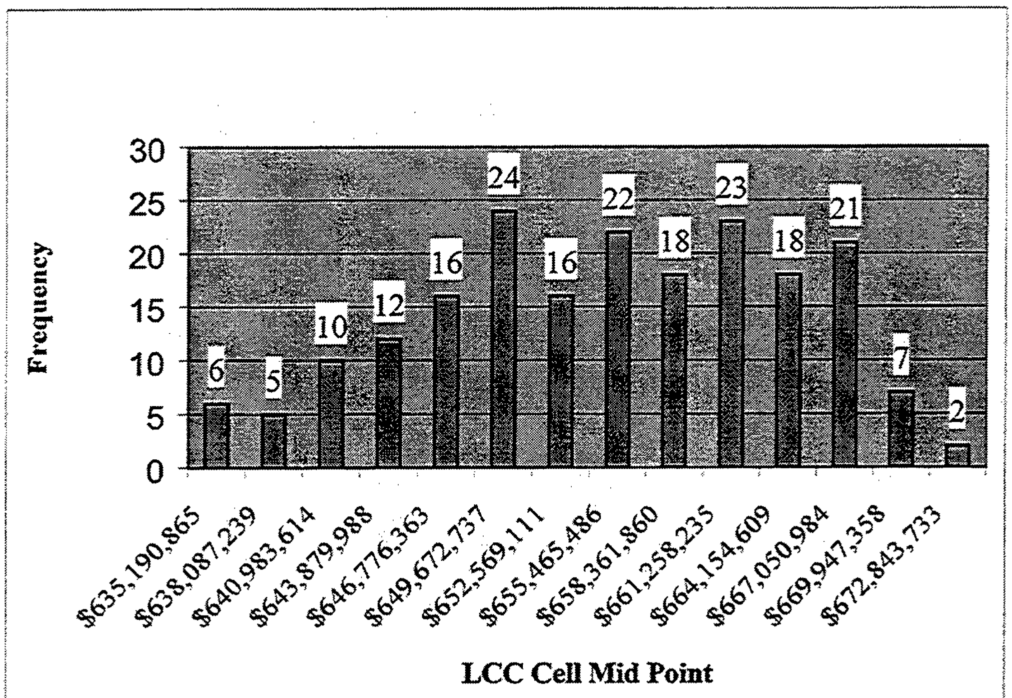

Figure 30: ATACMS IA LCC Frequency (200 Runs) **[Source Data: Appendix D]**

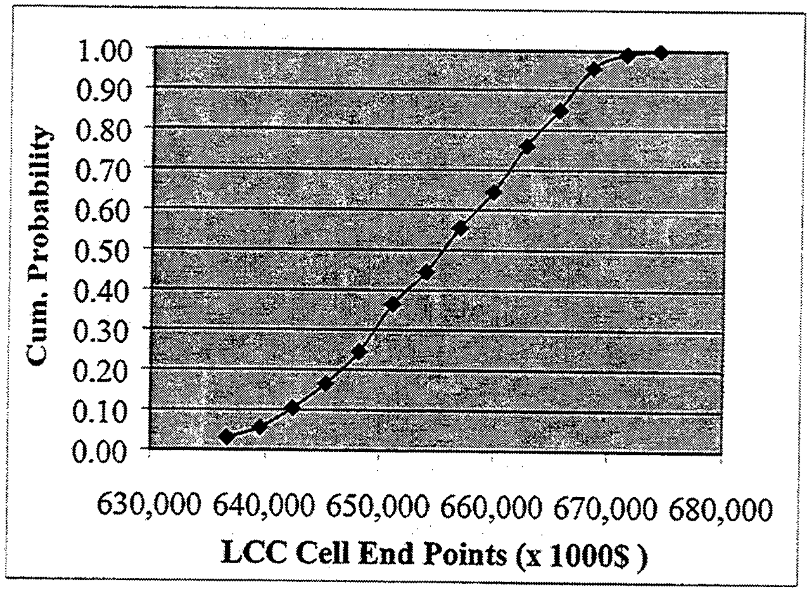

Figure 31: ATACMS IA LCC Cumulative Probability Distribution [Source Data: Appendix D]

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The acquisition of major systems requires long term cost commitments by the acquiring organizations, thus the resource allocation decisions must be based on life-cycle oriented analyses of so-called systems rather than analysis of the costs associated with up-front costs.

As is discussed in ATACMS IA case, system sustainment costs constitute a significant portion of system LCC costs, thus system development efforts and source selection decisions in an acquisition environment must be based on Total Ownership Cost evaluations of the alternative system solutions. Additionally, the implementation of alternative business practices such as IPPD, and Concurrent Engineering help the system developers and acquisition practitioners reduce the TOC of the system and increase the operational availability of the system. Furthermore, the PMs should develop cost reduction and operational availability improvement strategies, not only considering the system itself, but also considering the system and its support environment as a whole, otherwise these cost reduction and operational availability improvement efforts will not be as efficient and effective as expected.

The acquisition process, system development efforts, and cost estimation process which help decision makers allocate valuable resources to a program, or among programs have inherent uncertainties about future or expected program outcomes. Henceforth, the

cost uncertainty analyses about the expected program costs help the PMs uncover the costs risks associated with the program, develop realistic program cost estimates, and take appropriate measures such as PM's management reserve proactively, thus the program will continue without significant breaks resulting from the unavailability of funds.

B. RECOMMENDATIONS

The cost estimation and analysis of the estimate results for ATACMS IA system have been performed by utilizing the CASA cost estimation tool developed by the US Army Materiel Command.

Although the CASA model is very useful tool for developing LCC estimates, conducting sensitivity and uncertainty analyses by evaluating different system cost and supportability performance parameters and their impacts on system LCC and operational availability; the CASA should be improved in a way that enhances those capabilities, integrates the cost estimation techniques to the CASA such as incorporation of a data analysis and regression module, and includes all the statistical distribution functions, which are relevant to system performance and cost behaviors.

APPENDIX A. CASA MODEL INPUTS

INFLATION AND DISCOUNT RATE DATA (1994-2020)														
YEAR	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
INFLATION	2.00%	1.90%	2.00%	2.20%	2.20%	2.30%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%
DISCOUNT	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%
YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
INFLATION	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	
DISCOUNT	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	

RDT&E COST DISTRIBUTION BY CATEGORY (%)	
Research & Development	29.00%
Demonstration & Validation	12.00%
System/Project Management	19.00%
System Test & Evaluation	15.00%
Training	3.00%
Data	4.00%
Software Center	17.00%
Other	1.00%

RDT&E COST DATA (THEN YEAR $)				
YEAR	1994	1995	1996	1997
COST	$25,352,000	$36,337,000	$25,439,000	$8,529,000

SYSTEM PRODUCTION COST DATA

NAME	Cost	Year Exp
PRODUCT. TOOLING COS	$100,000	1997
PRODCT. START-UP	$ 50,000	1996
NON-REC. PROD. ENG.	$100,000	1996
BASE UNIT COST	$700,000	1997
INSTAL. COST	$10,000	1997

LEARNING CURVE SLOPE	90.00%
PROD. RATE SLOPE	95.00%

PRODUCTION SCHEDULE

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL
QUANTITY	14	96	107	120	120	130	130	50	767

SYSTEM SHIPPING AND STORAGE CONTAINERS

Year When Cost Incurred:	1997
Number of Containers:	20
Unit Cost ($)	$15,000
Year Dollars Expressed:	1997

SYSTEM HARDWARE DATA

	COST ME	QPHL	MTBF	K	MTTR	WEIGHT	SPARES T	LRPR	LREM	RTOK	MCPR	NRTS	NRTS TAT	COND	YRCE
GMLA	$500,000	1	10,000.00	1.00	30.00	3,923.00	2.00	Depot	Depot	0.00	$500	0.00	0.00	0.00	1997
Missile	$450,000	1	12,500.00	1.00	25.00	2,891.00	1.50	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Navigation and Guidance Se	$150,000	1	50,000.00	1.00	20.00		2.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Missile Nose	$50,000	1	142,858.00	1.00	20.00		1.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
IMOS	$100,000	1	76,923.00	1.00	40.00		3.00	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
Control Section Assembly	$100,000	1	33,333.00	1.00	20.00		3.00	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
Control Actuation System	$30,000	1	100,000.00	1.00	25.00		2.00	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
Power Batteries*	$25,000	2	200,000.00	1.00	10.00	20.00	1.50	Depot	Depot	0.01	$500	0.00	0.00	0.00	1997
Electrical Harness	$40,000	1	200,000.00	1.00	20.00		2.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Fin Assemblies	$7,500	4	800,000.00	1.00	10.00		2.00	Depot	Depot	0.00	$500	0.00	0.00	0.00	1997
Boattail Structure	$30,000	1	200,000.00	1.00	20.00		1.50	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Payload Section	$100,000	1	100,000.00	1.00	20.00		2.00	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
Skin Severence System	$40,000	1	333,333.00	1.00	25.00		2.00	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
M-74 Grenades*	$67	300	500,000.00	1.00	5.00	1.30	2.00	Depot	Depot	0.00	$500	1.00	2.00	0.00	1997
Electronic Safe/Arm Devic	$2,000	1	500,000.00	1.00	10.00		2.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
GPS Antenna	$20,000	1	333,333.00	1.00	20.00		1.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Solid Rocket Motor	$100,000	1	100,000.00	1.00	10.00		1.50	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
Motor Case	$5,000	1	500,000.00	1.00	5.00		1.50	Depot	Depot	0.00	$500	0.00	0.00	0.00	1997
Propellent	$2,000	1	500,000.00	1.00	10.00		1.00	Depot	Depot	0.00	$500	1.00	1.00	0.00	1997
Insulation Liner	$10,000	1	166,667.00	1.00	10.00		1.00	Depot	Depot	0.02	$500	0.00	0.00	0.00	1997
nozzle	$5,000	1	500,000.00	1.00	10.00		2.00	Depot	Depot	0.00	$500	0.00	0.00	0.00	1997
Igniter Arm/Fire Assy.	$10,000	1	125,000.00	1.00	10.00		1.50	Depot	Depot	0.05	$500	0.00	0.00	0.00	1997
EALP	$50,000	1	50,000.00	1.00	10.00	1,032.00	1.00	General Su	General Su	0.00	$500	0.80	1.00	0.00	1997
Forward Cover and Seal	$5,000	1	200,000.00	1.00	5.00		1.00	General Su	General Su	0.00	$500	0.80	2.00	0.00	1995
AFT Cover and Seal	$5,000	1	200,000.00	1.00	5.00		1.00	General Su	General Su	0.00	$500	0.75	1.00	0.00	1997
Weld Container	$40,000	1	100,000.00	1.00	15.00		1.00	General Su	General Su	0.00	$500	0.50	1.00	0.00	1997

	COST RISK DATA						PERFORMANCE PARAMETER RISK DATA	MTBF			MTTR		
	DISTRIBUTIO	MEAN	SD	MODE	LOW VALUE	HIDH VALUE	DISTRII	MEAN	SD	DISTRIBU	MODE	LOW VAL	HIGH VALUE
GMLA	Normal	700,000.00	100,000.00				Normal	10,000.00	1,000.00	Uniform		25.00	35.00
Missile	Normal	650,000.00	70,000.00				Normal	12,500.00	1,250.00	Uniform		20.00	30.00
Navigation and Guidance Se	Triangular			200,000.00	180,000.00	215,000.00	Normal	50,000.00	5,000.00	Uniform		15.00	25.00
Missile Nose	Uniform				40,000.00	60,000.00	Normal	142,258.00	10,000.00	Uniform		15.00	25.00
IMGS	Triangular			150,000.00	120,000.00	160,000.00	Normal	76,923.00	5,000.00	Uniform		35.00	45.00
Control Section Assembly	Triangular			250,000.00	200,000.00	270,000.00	Normal	33,333.00	3,000.00	Uniform		15.00	25.00
Control Actuation System	Triangular			100,000.00	90,000.00	120,000.00	Normal	100,000.00	5,000.00	Uniform		20.00	30.00
Power Batteries*	Normal	25,000.00	2,500.00				Normal	200,000.00	10,000.00	Uniform		8.00	12.00
Electrical Harness	Triangular			40,000.00	35,000.00	42,000.00	Normal	200,000.00	10,000.00	Uniform		15.00	25.00
Fin Assemblies	Triangular			7,500.00	7,000.00	7,800.00	Normal	800,000.00	5,000.00	Uniform		8.00	12.00
Boattail Structure	Normal	30,000.00	3,000.00				Normal	200,000.00	5,000.00	Uniform		18.00	22.00
Payload Section	Normal	100,000.00	5,000.00				Normal	100,000.00	7,500.00	Uniform		16.00	24.00
Skin Severence System	Normal	40,000.00	2,000.00				Normal	333,333.00	15,000.00	Uniform		20.00	30.00
M-74 Grenades*	Triangular			67.00	60.00	70.00	Normal	500,000.00	10,000.00	Triangular	5.00	4.00	6.00
Electronic Safe/Arm Devi	Normal	20,000.00	3,000.00				Normal	500,000.00	10,000.00	Uniform		3.00	7.00
GPS Antenna	Triangular			20,000.00	15,000.00	22,000.00	Normal	333,333.00	6,000.00	Uniform		18.00	22.00
Solid Rocket Motor	Triangular			100,000.00	95,000.00	110,000.00	Normal	50,000.00	2,500.00	Uniform		8.00	12.00
Motor Case	Normal	5,000.00	500.00				Normal	500,000.00	20,000.00	Uniform		4.00	6.00
Propellant	Normal	20,000.00	2,000.00				Normal	500,000.00	10,000.00	Uniform		8.00	12.00
Insulation Liner	Normal	10,000.00	2,000.00				Normal	166,667.00	5,000.00	Uniform		8.00	12.00
nozzle	Triangular			5,000.00	4,500.00	6,000.00	Normal	500,000.00	5,000.00	Triangular	10.00	8.00	12.00
Igniter Arm/Fire Assy.	Normal	1,000.00	500.00				Normal	125,000.00	12,500.00	Uniform		7.00	13.00
EALP	Triangular			50,000.00	45,000.00	52,000.00	Normal	50,000.00	1,000.00	Uniform		8.00	12.00
Forward Cover and Seal	Normal	5,000.00	1,000.00				Normal	200,000.00	10,000.00	Uniform		3.00	7.00
AFT Cover and Seal	Triangular			5,000.00	4,000.00	5,500.00	Normal	200,000.00	12,000.00	Uniform		3.00	7.00
Weld Container	Constant	40,000.00					Normal	100,000.00	5,000.00	Uniform		12.00	18.00

DEPLOYMENT&RETIREMENT SCHEDULE

YEAR	JANUARY	FEBRUAR	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMI	OCTOBEI	NOVEMB	DECEMBI
1997	0	0	0	0	0	0	0	0	7	7	0	0
1998	0	8	8	8	8	8	8	8	8	8	8	8
1999	8	8	8	8	8	8	8	8	9	10	10	10
2000	12	10	10	10	10	10	10	10	10	10	10	10
2001	10	10	10	10	10	10	10	10	10	10	10	[illegible]
2002	10	10	10	10	10	10	10	12	12	10	12	[illegible]
2003	12	12	12	12	12	12	10	10	10	10	10	10
2004	10	10	10	10	10	10	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	-20	-20	-20	0	0	-20	-20	-20	0	0
2016	-20	-40	0	0	0	0	0	-60	0	0	0	0
2017	0	0	0	-60	0	0	0	0	0	-60	0	0
2018	0	0	0	-60	0	0	0	0	0	-60	0	0
2019	0	0	0	-70	0	0	0	0	-70	0	0	0
2020	0	0	0	-25	0	0	0	0	-22	0	0	0

NOTE: NEGATIVE NUMBERS DENOTE THE QUANTITY OF SYSTEMS THAT PUT OUT OF SERVICE EITHER BY FIRING OR DISPOSAL.

TRAINING COST DATA

INITIAL TRAINING

	COST	COURSE N.	Year	Days	Hours	DEV. COST	# OF TRAINEE
Per Diem Allowance per Day per Train	$120	Depot Pers	1996	20	120.00	10.00	50
Year Dollars Expressed for Per Diem:	1997	GS Personn	1996	20	100.00	10.00	100
Avg. Round-trip Transportation Costs (	$500	Launcher O	1997	2	10.00	5.00	150
Year Dollars Expressed for Round-trip	1997						

RECURRING TRAINING

	General Sup	Depot
New Personel Training Hours:	50.00	75.00
Develop Cost per Hour ($/Hr):	50.00	50.00
Year Dollars Expressed:	1997	1997
Annual Turnover Rate:	0.25	0.25

TRAINING DEVICES

Name	Year	Quantity	Unit Cost	Yr Exp
MTD Train	1996	15	25,000.00	1998
EOD Traine	1997	20	10,000.00	1996

NOTE: OPERATOR RECURRING TRAINING EXCLUDED SINCE OPERATORS ARE CONTINOUSLY TRAINED IN THEIR DAILY ACTIVITIES.

INITIAL TECHNICAL DOCUMENTATION

		# OF PAGE	($/Page)		# OF COPIES
D. Name	Year	Pages	Develop	Publish	Copies
Tecnical Manuals	1997	500	15.00	0.25	100

RECURRING TECHNICAL DOCUMENTATION (Per Year)

	General Supp	Depot
Number of Pages Revise	50	50
Cost per Page ($/Pg):	10.00	10.00
Year Dollars Expressed:	1997	1997

OPERATIONS AND MAINTENANACE DATA

MAINTENANCE LEVEL INFORMATION

	Level 0	Level 1	Comments
No. of Operating Systems per Loc.:	80	380	
Maintenance Labor Rate ($/hr):	$25	$30	
Year Dollars Expressed MLR:	1997	1997	
Software Maintenance Labor Rate ($/h	$50	$60	
Year Dollars Expressed SMLR:	1997	1997	
Available Support Equip. Hours per Mo	100.00	180.00	
Support Equipment Utilization Factor:	0.75	0.75	
Initial Spt Eq Spares Cost Portion:	0.25	0.25	
Spares Confidence Level:	0.90	0.95	
Earned Hour Ratio:	1.00	1.00	
System Repair Elapsed Time (Hours):	15.00	120.00	

SUPPORT EQUIPMENT MAINTENANCE DATA

	Unit	Annual Maint.	
Item Name	Cost	Cost Portio	Year Exp
MTD	$50,000	0.10	1997
MTFE	$100,000	0.20	1995

TRANSPORTATION COST DATA

Cost ($)p	$1
General Support and Depot :	
Paperwor	$30
Year Do	1997

SOFTWARE DEVELOPMENT AND MAINTAINANCE COST DATA:							
INITIAL SOFTWARE DEVELOPMENT				**SOFTWARE MAINTAINANCE**			
Cost Driver Product of Effort Multipliers (PEM)				YEAR			
				1994	0.00		
	Rating	PEM		1995	0.00		
Product Attributes				1996	0.01		
Required Software Reliability	High	1.15		1997	0.01		
Data Base Size	Nominal	1.00		1998	0.01		
Product Complexity	High	1.15		1999	0.01		
				2000	0.01		
Computer Attributes				2001	0.01		
Execution Time Constraints	Very High	1.30		2002	0.01		
Main Storage Constraints	Very High	1.21		2003	0.01		
Virtual Machine Volatility	Nominal	1.00		2004	0.01		
Computer Turnaround Time	Nominal	1.00		2005	0.01		
				2006	0.01		
Personal Attributes				2007	0.01		
Analyst Capability	Nominal	1.00		2008	0.01		
Applications Experience	High	0.91		2009	0.01		
Programmer Capability	High	0.86		2010	0.01		
Virtual Machine Experience	Nominal	1.00		2011	0.01		
Programming Language Experience	Nominal	1.00		2012	0.01		
				2013	0.01		
Project Attributes				2014	0.01		
Use of Modern Programming Practic	High	0.91		2015	0.01		
Use of Software Tools	High	0.91		2016	0.01		
Required Development Schedule	Nominal	1.00		2017	0.01		
				2018	0.01		
Thousands of New/Modified Source Li	570.00			2019	0.01		
Thousands of Reused Source Lines:	40.00			2020	0.01		
Thousands of Retained Source Lines:	0.00						
Software Development Labor Rate ($/I	$60						
Year Dollars Expressed for SDLR	1997						
Portion of Initial Software Development by Year							
	1994	**1995**	**1996**	**1997**			
Portion	40%	50%	8%	2%			
NOTE: SW MAINTENACE EFFORTS ARE EXPRESSED							
BY FRACTION OF INTIAL EFFORTS BY YEAR.							

APPENDIX B. ATACMS IA LCC ESTIMATION RESULTS

	ATACMS 1A LCC Estimation		
TOTAL LIFE CYCLE COST			
Total RDT&E Cost	$95,657,000		
Total Acquisition Cost	$293,927,288		
Total Operation and Support Cost	$269,103,010		
TOTAL LIFE CYCLE COST	$658,687,298		
RDT&E Cost			
	Distribution		
Research & Development	29%	$27,740,530	
Demonstration and Validation	12%	$11,478,840	
System/Project Management	19%	$18,174,830	
System Test & Evaluation	15%	$14,348,550	
Training	3%	$2,869,710	
Data	4%	$3,826,280	
Software Center	17%	$16,261,690	
Other	1%	$956,570	
Total RDT&E Cost		**$95,657,000**	
Operation and Support Costs			
	General Support	Depot	Total
Repair Labor	$1,113,077	$97,808,670	$98,921,747
Support Equip Maint	$0	$18,518,333	$18,518,333
Recurring Training	$58,854	$1,018,875	$1,077,729
Repair Prts and Mtl	$2,225,708	$87,066,942	$89,292,651
Consumables	$222,571	$8,706,694	$8,929,265
Condemnation Spares	$32,279	$8,918,493	$8,950,772
Tech Data Revisions	$11,667	$11,667	$23,333
Transportation	$3,782,680	$4,180,716	$7,963,397
Recrring Facilities	$1,803,333	$6,666,667	$8,470,000
Recrring Item Mgmt	$272,833	$171,200	$444,033
Sftware Maintenance	$0	$26,511,749	$26,511,749
TOTAL O & S COST	$9,523,003	$259,580,007	$269,103,010
(NOT CONSIDERING WARRANTY)			

CONSTANT ANNUAL COSTS (2001 DOLLARS x 1000)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
RDT&E COSTS														
TOTAL RDT&E COSTS	25,352	36,337	25,439	9,539	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACQUISITION COSTS														
TOOLING AND TEST EQUIPMENT	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
START UP	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SYSTEM ACQUISITION	0.0	0.0	0.0	6,173	26,139	24,493	25,097	23,746	24,527	23,708	9,594	0.0	0.0	0.0
SHIPPING CONTAINER	0.0	0.0	0.0	300.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRE-PROD ENG CHNGE	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRE-PROD REFURBISH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTALLATION	0.0	0.0	0.0	140.0	890.0	1,030	1,220	1,200	1,290	1,320	600.0	0.0	0.0	0.0
SUPPORT EQUIPMENT	0.0	0.0	0.0	187.5	812.5	1,000	1,187	1,187	1,250	1,125	750.0	0.0	0.0	0.0
HARDWARE SPARES	0.0	0.0	0.0	412.5	871.5	777.0	906.5	1,374	1,133	610.0	1,069	0.0	0.0	0.0
SPARES REUSABLE CONTAINERS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TECH DATA	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	776.0	152.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRAINING DEVICES	0.0	0.0	375.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NEW FACILITIES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL ITEM MGMT	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL SOFTWARE DEVELOPME	42,418	53,023	8,483	2,120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISC ACQ COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WARRANTY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ACQ COST	42,418	53,023	9,834	9,759	28,713	27,300	28,411	27,508	28,190	26,763	12,013	0.0	0.0	0.0
OPERATION & SUPPORT COSTS														
OPERATION LABOR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
REPAIR LABOR	0.0	0.0	0.0	31.4	445.4	1,192	2,088	3,010	3,946	4,957	5,293	5,889	5,889	5,889
SUPPORT EQUIP MAINTENANCE	0.0	0.0	0.0	9.3	140.0	280.0	445.0	610.0	790.0	940.0	1,050	1,050	1,050	1,050
RECURRING TRAINING	0.0	0.0	0.0	6.7	8.5	16.1	25.8	35.6	45.3	55.7	60.5	60.5	60.5	60.5
REPAIR PARTS AND MATERIALS	0.0	0.0	0.0	28.3	402.0	1,076	1,885	2,717	3,562	4,501	5,229	5,316	5,316	5,316
CONSUMABLES	0.0	0.0	0.0	2.8	40.2	107.7	155.5	271.7	356.3	450.2	523.0	531.6	531.6	531.6
CONDEMNATION SPARES	0.0	0.0	0.0	2.8	40.3	107.9	189.0	272.4	357.1	451.3	524.2	532.9	532.9	532.9
TECH DATA REVISION	0.0	0.0	0.0	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
TRANSPORTATION	0.0	0.0	0.0	2.5	35.9	96.0	168.1	242.3	317.7	401.5	466.4	474.1	474.1	474.1
RECURRING FACILITIES	0.0	0.0	0.0	45.0	145.0	155.0	175.0	310.0	330.0	340.0	475.0	475.0	475.0	475.0
RECURRING ITEM MGMT	0.0	0.0	0.0	1.7	6.6	8.1	11.1	15.6	18.6	20.1	24.6	24.6	24.6	24.6
SOFTWARE MAINTENANCE	0.0	0.0	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060
CONTRACTOR SERVICES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ENGINEERING CHANGES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISC O & S COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WARRANTY COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL O & S COSTS	0.0	0.0	1,060	1,190	1,325	4,101	6,237	8,546	10,785	13,309	15,208	15,415	15,415	15,415
TOTAL COSTS	67,770	89,360	36,334	19,479	31,028	31,401	34,649	36,054	38,976	39,973	27,221	15,415	15,415	15,415
PERCENT OF LCC	10.29	13.57	5.52	2.96	4.71	4.77	5.26	5.47	5.92	6.07	4.13	2.34	2.34	2.34

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	TOTAL	% LCC
RDT&E COSTS															
TOTAL RDT&E COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95,657	14.52
ACQUISITION COSTS															
TOOLING AND TEST EQUIPMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.02
START UP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.01
SYSTEM ACQUISITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	163,480	24.82
SHIPPING CONTAINER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	300.0	0.05
PRE-PROD ENG CHNGE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.02
PRE-PROD REFURBISH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INSTALLATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,690	1.16
SUPPORT EQUIPMENT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,500	1.14
HARDWARE SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,154	1.09
SPARES REUSABLE CONTAINERS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INITIAL TECH DATA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.00
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	928.8	0.14
TRAINING DEVICES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	575.0	0.09
NEW FACILITIES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INITIAL ITEM MGMT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.00
INITIAL SOFTWARE DEVELOPME	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	106,047	16.10
MISC ACQ COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
WARRANTY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
TOTAL ACQ COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	293,927	44.62
OPERATION & SUPPORT COSTS															
OPERATION LABOR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
REPAIR LABOR	5,889	5,889	5,889	5,889	5,889	5,889	5,889	5,390	4,341	3,585	2,664	1,621	928.5	98,921	15.02
SUPPORT EQUIP MAINTENANCE	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	840.0	700.0	560.0	395.0	210.0	18,518	2.81
RECURRING TRAINING	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	49.8	41.6	32.3	22.6	11.9	1,077	0.16
REPAIR PARTS AND MATERIALS	5,316	5,316	5,316	5,316	5,316	5,316	5,316	4,565	3,918	3,236	2,405	1,463	838.1	89,292	13.56
CONSUMABLES	531.6	531.6	531.6	531.6	531.6	531.6	531.6	486.6	391.8	323.7	240.5	146.1	83.8	8,929	1.36
CONDEMNATION SPARES	532.9	532.9	532.9	532.9	532.9	532.9	532.9	487.7	392.8	324.5	241.1	146.7	84.0	8,950	1.36
TECH DATA REVISION	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	23.3	0.00
TRANSPORTATION	474.1	474.1	474.1	474.1	474.1	474.1	474.1	433.9	349.5	288.7	214.5	130.5	74.7	7,963	1.21
RECURRING FACILITIES	475.0	475.0	475.0	475.0	475.0	475.0	475.0	475.0	330.0	320.0	310.0	165.0	145.0	8,470	1.29
RECURRING ITEM MGMT	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6	18.6	17.1	15.6	9.6	6.6	444.0	0.07
SOFTWARE MAINTENANCE	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	1,060	26,511	4.02
CONTRACTOR SERVICES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
ENGINEERING CHANGES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
MISC O & S COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
WARRANTY COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
TOTAL O & S COSTS	15,415	15,415	15,415	15,415	15,415	15,415	15,415	14,335	11,693	9,899	7,745	5,162	3,444	269,103	40.85
TOTAL COSTS	15,415	15,415	15,415	15,415	15,415	15,415	15,415	14,335	11,693	9,899	7,745	5,162	3,444	658,687	
PERCENT OF LCC	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.18	1.78	1.50	1.18	0.78	0.52		100.00

ANNUAL COSTS (THEN YEAR DOLLARS x 1000)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	TOTAL	% LCC
RDT&E COSTS																													
TOTAL RDT&E COSTS	21,829	31,926	22,784	7,794	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84,335	12.13
ACQUISITION COSTS																													
TOOLING AND TEST EQUIPMENT	0.0	0.0	89.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.6	0.01
START UP	0.0	0.0	0.0	45.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.7	0.01
SYSTEM ACQUISITION	0.0	0.0	0.0	5,642	24,426	23,403	24,545	24,269	25,618	25,308	10,466	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	163,679	23.54
SHIPPING CONTAINER	0.0	0.0	0.0	274.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	274.2	0.04
PRE-PROD ENG CHNGE	0.0	0.0	89.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.6	0.01
PRE-PROD REFURBISH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INSTALLATION	0.0	0.0	0.0	127.9	822.3	984.2	1,193	1,226	1,336	1,409	654.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,754	1.12
SUPPORT EQUIPMENT	0.0	0.0	0.0	171.4	759.3	955.5	1,161	1,213	1,305	1,200	818.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,585	1.09
HARDWARE SPARES	0.0	0.0	0.0	377.0	814.4	742.4	886.6	1,404	1,183	651.2	1,166	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,225	1.04
SPARES REUSABLE CONTAINERS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INITIAL TECH DATA	0.0	0.0	0.0	18.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	0.00
INITIAL TRAINING	0.0	0.0	695.0	139.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	834.6	0.12
TRAINING DEVICES	0.0	0.0	335.9	182.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	518.7	0.07
NEW FACILITIES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
INITIAL ITEM MGMT	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.00
INITIAL SOFTWARE DEVELOPME	36,525	46,588	7,598	1,938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92,649	13.33
MISC ACQ COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
WARRANTY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
TOTAL ACQ COST	36,525	46,588	8,808	8,919	26,822	26,085	27,766	28,113	29,444	28,569	13,105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	280,768	40.38
OPERATION & SUPPORT COSTS																													
OPERATION LABOR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
REPAIR LABOR	0.0	0.0	0.0	28.7	416.2	1,139	2,042	3,076	4,122	5,323	6,320	6,566	6,710	6,858	7,009	7,163	7,321	7,482	7,646	7,815	7,987	7,471	6,148	5,191	3,942	2,451	1,434	121,671	17.50
SUPPORT EQUIP MAINTENANCE	0.0	0.0	0.0	7.6	130.8	267.5	435.2	623.4	815.1	1,003	1,145	1,170	1,196	1,222	1,249	1,277	1,305	1,334	1,363	1,393	1,424	1,455	1,189	1,013	828.5	597.3	324.5	22,754	3.28
RECURRING TRAINING	0.0	0.0	0.0	6.1	7.9	15.4	25.2	36.4	47.3	59.4	66.0	67.5	68.9	70.5	72.0	73.6	75.2	76.9	78.6	80.3	82.0	83.9	70.5	60.2	47.7	34.2	18.4	1,324	0.19
REPAIR PARTS AND MATERIALS	0.0	0.0	0.0	25.9	375.7	1,028	1,843	2,776	3,721	4,805	5,705	5,927	6,057	6,190	6,327	6,466	6,608	6,754	6,902	7,054	7,209	6,743	5,550	4,685	3,558	2,313	1,295	109,527	15.75
CONSUMABLES	0.0	0.0	0.0	2.6	37.6	102.9	184.4	277.7	372.1	480.5	570.5	592.7	605.8	619.1	632.7	646.6	660.9	675.4	690.3	705.4	721.0	674.4	555.0	468.6	355.8	221.3	129.5	10,982	1.58
CONDEMNATION SPARES	0.0	0.0	0.0	2.6	37.7	103.1	184.8	278.3	373.0	481.7	571.9	594.2	607.2	620.6	634.2	648.2	662.5	677.0	691.9	707.1	722.7	676.0	556.4	469.7	356.7	221.8	129.8	11,009	1.58
TECH DATA REVISION	0.0	0.0	0.0	0.3	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.5	1.5	1.5	25.5	0.00
TRANSPORTATION	0.0	0.0	0.0	2.3	33.5	91.7	164.4	247.6	331.9	428.6	508.8	528.6	540.2	552.1	564.3	576.7	589.4	602.3	615.6	629.1	643.0	601.4	495.0	417.9	317.3	197.4	115.5	9,794	1.41
RECURRING FACILITIES	0.0	0.0	0.0	41.1	135.5	148.1	171.2	316.8	344.7	362.9	518.2	529.6	541.3	553.2	565.3	577.8	590.5	603.5	616.7	630.3	644.2	658.4	467.4	463.2	458.6	249.5	224.1	10,412	1.50
RECURRING ITEM MGMT	0.0	0.0	0.0	1.5	6.1	7.7	10.8	15.9	19.4	21.4	26.8	27.4	28.0	28.6	29.3	29.9	30.6	31.2	31.9	32.6	33.3	34.1	26.3	24.7	23.1	14.5	10.2	545.5	0.08
SOFTWARE MAINTENANCE	0.0	0.0	949.8	969.2	991.0	1,013	1,037	1,083	1,107	1,132	1,156	1,182	1,208	1,235	1,262	1,289	1,318	1,347	1,376	1,407	1,438	1,469	1,502	1,535	1,569	1,603	1,638	31,874	4.58
CONTRACTOR SERVICES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
ENGINEERING CHANGES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
MISC O & S COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
WARRANTY COSTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
TOTAL O & S COSTS	0.0	0.0	949.8	1,087	2,172	3,919	6,109	8,734	11,265	14,100	16,591	17,187	17,566	17,952	18,347	18,751	19,163	19,585	20,016	20,456	20,906	19,869	16,563	14,331	11,458	7,895	5,322	330,204	47.49
TOTAL COSTS	58,354	78,514	32,541	17,802	28,995	30,004	33,887	36,847	40,709	42,669	29,696	17,187	17,566	17,952	18,347	18,751	19,163	19,585	20,016	20,456	20,906	19,869	16,563	14,331	11,458	7,895	5,322	695,308	
PERCENT OF LCC	8.39	11.29	4.68	2.56	4.17	4.32	4.87	5.30	5.85	6.14	4.27	2.47	2.53	2.58	2.64	2.70	2.76	2.82	2.88	2.94	3.01	2.86	2.38	2.06	1.65	1.12	0.77		100.00

	ATACMS 1A LCC	4/20/2001	Acquisition Costs				
PRODUCTION COST							
	TOOLING AND TEST EQUIPMENT						
	FRP Production tooling				$100,000		$100,000
						$100,000	
	START UP					$50,000	
	MANUFACTURING COSTS						
		767 Systems		213,142 Avg per System		$163,480,043	
		20 Ship/Store Containers		15000 per set		$300,000	
							$163,830,043
	PRE-PRODUCTION ENGINEERING CHANGES						
		Non-RecurringManufacturing Engineering Services			$100,000		$100,000
	INSTALLATION COST						
		767 Systems		10,000 per System			$7,670,000
SUPPORT EQUIPMENT			QTY	COST/UNIT			
		MTFE	45	$100,000	$4,500,000		
		MTD	30	$50,000	$1,500,000		
			SPT EQ SPARE PARTS		$1,500,000		
						$7,500,000	$7,500,000
SPARES			QTY	COST/UNIT			
	General Support						
		Forward Cover and Seal	10	$5,000	$50,000		
		AFT Cover and Seal	10	$5,000	$50,000		
		Weld Container	10	$40,000	$400,000		
						$500,000	
	Depot						
		Missile Nose	9	$50,000	$450,000		
		IMGS	36	$100,000	$3,600,000		
		Power Batteries	18	$25,000	$450,000		
		Electrical Harness	12	$40,000	$480,000		
		Skin Severence System	9	$40,000	$360,000		
		Electronic Safe/Arm Device	6	$2,000	$12,000		
		GPS Antenna	6	$20,000	$120,000		
		Fin Assemblies	12	$7,500	$90,000		
		Boattail Structure	12	$30,000	$360,000		
		Motor Case	6	$5,000	$30,000		
		Propellant	6	$2,000	$12,000		
		Insulation Liner	9	$10,000	$90,000		
		nozzle	6	$5,000	$30,000		
		Igniter Arm/Fire Assy.	15	$10,000	$150,000		
		Forward Cover and Seal	6	$5,000	$30,000		
		AFT Cover and Seal	6	$5,000	$30,000		
		Weld Container	9	$40,000	$360,000		
						$6,654,000	
							$7,154,000
TECHNICAL DATA			PAGES	COST/PAGE			
	DEVELOPMENT COST						
		Tecnical Manuals	500	$15	$7,500		
						$7,500	
	PRINTING COST					$12,500	
							$20,000
TRAINING			HOURS	COST/HOUR			
	DEVELOPMENT COST						
		GS Personnel	100.00	$10	$1,000		
		Depot Personnel	120.00	$10	$1,200		
		Launcher Operator Orientation	10.00	$5	$50		
						$2,250	
	INSTRUCTOR COST					$28,000	
	TRAINEE COST						
		LABOR			$352,500		
		PER DIEM			$396,000		
		TRANSPORTATION			$150,000		
						$898,500	
	TRAINING DEVICES		QTY	COST/UNIT			
		MTD Trainer	15	$25,000	$375,000		
		EOD Trainer Set	20	$10,000	$200,000		
						$575,000	
							$1,503,750
ITEM MANAGEMENT							$2,500
INITIAL SOFTWARE DEVELOPMENT ESTIMATE							
		SCHEDULE	EFFORT				
		(MONTHS)	(MAN-MONTHS)	COST			
NEW AND MODIFIED SOFTWARE							
Plans and Requirements		6.44	1,204.97	11,567,756.78			
Product Design		6.87	2,190.86	21,032,285.05			
Programming		10.73	3,614.92	34,703,270.33			
Integration and Test		18.88	3,943.55	37,858,113.09			
Totals		42.92	10,954.32	$105,161,425			
REUSED AND RETAINED SOFTWARE							
Plans and Requirements		0.05	5.53	53,134.19			
Product Design		0.06	8.30	79,701.29			
Programming		0.09	23.98	230,248.17			
Integration and Test		0.16	54.43	522,486.24			
Totals		0.36	92.25	$885,570			
OVERALL TOTALS		43.28	11,046.56	$106,046,995			
							$106,046,995
TOTAL ACQUISITION COST (NOT CONSIDERING WARRANTY)							$293,927,288

APPENDIX C. SENSITIVITY ANALYSIS RESULTS

SENSITIVITY ANALYSIS — ATACMS 1A LCC Estimation

Results of MEAN TIME BETWEEN FAILURES (MTBF) Sensitivity Runs *

SENSITIVITY = $-3060134 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation an Support Cost	Total LCC ($)	Operational Availability
40	407,932,288	617,966,278	1,025,898,56	0.813293
70	394,770,288	368,814,684	763,584,973	0.884031
100	389,584,288	269,103,009	658,687,298	0.915895
140	386,130,288	202,617,754	588,748,042	0.938446
200	383,498,288	152,778,781	536,277,069	0.956102

Results of UNIT COST (UC) Sensitivity Runs *

SENSITIVITY = $161048 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation and Support Cost	Total LCC ($)
60	386,722,688	265,522,700	652,245,389
80	388,153,488	267,312,855	656,466,343
100	389,584,288	269,103,009	658,687,298
125	391,372,788	271,340,702	662,713,491
150	393,161,288	273,578,396	666,739,684

Results of MEAN TIME TO REPAIR (MTTR) Sensitivity Runs *

SENSITIVITY = $999293 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation an Support Cost	Total LCC ($)
40	389,584,288	209,149,586	598,733,874
70	389,584,288	239,127,235	628,711,523
100	389,584,288	269,103,009	658,687,298
140	389,584,288	309,064,521	698,648,809
200	389,584,288	369,036,507	758,620,795

Results of MAINTENANCE PERSONEL TURNOVER RATE (TOR) Sensitivity Runs *

SENSITIVITY = $10715 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation and Support Cost	Total LCC ($)
40	389,584,288	268,460,122	658,044,410
70	389,584,288	268,781,566	658,365,854
100	389,584,288	269,103,009	658,687,298
140	389,584,288	269,531,601	659,115,889
200	389,584,288	270,174,489	659,758,777

Results of PRODUCTION QUANTITY SLOPE Sensitivity Runs *

SENSITIVITY = $525162220 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation an Support Cost	Total LCC ($)
0.8	256,929,678	269,103,009	526,032,688
0.85	273,630,307	269,103,009	542,733,317
0.9	298,686,590	269,103,009	567,789,600
0.95	335,704,011	269,103,009	604,807,021
1	389,584,288	269,103,009	658,687,298

Results of PRODUCTION RATE SLOPE Sensitivity Runs *

SENSITIVITY = $525451500 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation and Support Cost	Total LCC ($)
0.8	263,446,233	269,103,009	532,549,243
0.85	281,720,861	269,103,009	550,823,871
0.9	307,240,107	269,103,009	576,343,117
0.95	342,263,958	269,103,009	611,366,968
1	389,584,288	269,103,009	658,687,298

Results of SPARES TURNAROUND TIME (TAT) Sensitivity Runs *

SENSITIVITY = $50772 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation an Support Cost	Total LCC ($)
40	386,505,288	269,103,009	655,608,298
70	388,001,788	269,103,009	657,104,798
100	389,584,288	269,103,009	658,687,298
140	391,592,788	269,103,009	660,695,798
200	394,628,788	269,103,009	663,731,798

Results of SPARES CONFIDENCE LEVEL (CL) Sensitivity Runs *

SENSITIVITY = $7082222 ($ / PERCENT OF BASELINE)

Percent of Baseline V	Acquisition Cost ($)	Operation and Support Cost	Total LCC ($)	Operational Availability
0.5	385,776,288	269,103,009	654,879,29	0.905642
0.75	387,047,288	269,103,009	656,150,29	0.910453
0.85	387,896,788	269,103,009	656,999,79	0.913573
0.95	388,963,288	269,103,009	658,066,29	0.915895
1	389,584,288	269,103,009	658,687,29	0.915895

MBT Sensitivity Analysis

Percent of Baseline		Operational Availability
50		0.961
75		0.93357
100		0.9159
125		0.897
150		0.8789
175		0.8615
200		0.8448

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APPENDIX D. COST RISK ANALYSIS RESULTS

	LCC MONTE CARLO RESULTS			
Minimum	Maximum	Mean	Standard Deviation	
$ 633,742,677.40	$ 674,291,920.00	$ 654,988,589.02	$ 9,192,608.21	
	LCC Frequency Table			
			LCC Cumulative Distributio	
Cell Mid Point	Frequency	Cell End Point	Cumulative Probability	
$ 635,190,864.64	6	636,639,051.87	0.03	
$ 638,087,239.11	5	639,535,426.34	0.06	
$ 640,983,613.58	10	642,431,800.81	0.11	
$ 643,879,988.05	12	645,328,175.29	0.17	
$ 646,776,362.52	16	648,224,549.76	0.25	
$ 649,672,736.99	24	651,120,924.23	0.37	
$ 652,569,111.46	16	654,017,298.70	0.45	
$ 655,465,485.94	22	656,913,673.17	0.56	
$ 658,361,860.41	18	659,810,047.64	0.65	
$ 661,258,234.88	23	662,706,422.12	0.76	
$ 664,154,609.35	18	665,602,796.59	0.85	
$ 667,050,983.82	21	668,499,171.06	0.96	
$ 669,947,358.29	7	671,395,545.53	0.99	
$ 672,843,732.77	2	674,291,920.00	1.00	

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